MANUAL TRAINING
Made Serviceable
to the School

BY

DR. WOLDEMAR GOETZE

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MANUAL TRAINING MADE SERVICEABLE TO THE SCHOOL

MANUAL TRAINING

Made Serviceable to the School

A PRACTICAL ATTEMPT TO UTILISE MANUAL TRAINING IN THE GENERAL INTEREST OF SCHOOL-WORK

BEING

A Graduated Course of Lessons in the Construction of Apparatus and Illustrative Appliances for various subjects

BY

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TRANSLATED INTO ENGLISH

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PREFACE TO THE ENGLISH EDITION

As the whole question of Manual Training has been discussed, the objections to it considered, and its historical development traced, by Dr. Götze in his Manual, published in the early part of the present year, it will be unnecessary to repeat here what is already on record in an accessible form. The special objects of the present volume are fully set forth in the two introductory chapters.

The impression would seem to prevail in some quarters that Manual Training is essentially a subject for primary schools, in which education proper is subordinated to the means of bread-winning. That, however, is not the view of its advocates, who claim that its educative qualities are such that no school can afford to ignore it. As many of the higher schools already possess workshops, it would be easy for them to make trial of the system. The expense is not greater than that involved by the common, unmethodical forms of handicraft as taught by the artisan. Perhaps the making of apparatus may commend itself to utilitarian minds by its practical value, and induce investigation of the whole matter.

In making the translation I have aimed at lucidity rather than finish, and have not shrunk from repetition or seeming redundancy of phrase if greater clearness seemed to result therefrom. Technical terms have been, as much as possible, avoided, and such only have been admitted as are of almost universal acceptance. With regard to the word *Anschauung*, as the Englishman who can translate it has not yet arisen, I have frequently evaded it, or resorted to some loose equivalent. Thus, *Anschauungsmittel* sometimes appears as "means of exhibiting" or "means illustrating." Neither Russell's "sense-impression" nor Hailman's "immediate perception" seem to me quite adequate, but I can make no better suggestion. However, with the caution I have given, misconception cannot easily arise.

It is perhaps hardly necessary to add, in conclusion: (1) that the sketches given are not working drawings, these must be made by the boys themselves; (2) that without *good* tools satisfactory results are not to be expected.

W. G. F.

[NOTE.—On *Anschauung*, see *Life of Pestalozzi*, by Roger de Guimps, translated by J. Russell; also, *The Education of Man* by Friedrich Fröbel, translated by W. N. Hailman.]

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MANUAL TRAINING MADE SERVICEABLE TO THE SCHOOL

I

HOW MAY MANUAL TRAINING SERVE THE SCHOOL?

(*An Address delivered at Leipzig in the "Lehrerbildungsanstalt für Knabenhandarbeit."*)

I HAVE the honour to-day to address myself to schoolmasters upon the service which Manual Training can render to the school. The nature of my subject and the shortness of the time at my disposal require me to leave all controversial matters aside. Thus I am not going to discuss the familiar question, whether the introduction of Manual Training into the school should be free or compulsory. You have no need to fear that I propose to win your sympathies for a cause which is alien to them. My only demand is for that which has already been conceded, I mean the existence, side by side with the school, of free workshops, directed by schoolmasters who volunteer for the work, and receive remuneration for the extra labour involved. This granted, I am content, and my only wish now is, as a teacher before teachers, to answer the question, How may manual work, voluntary but well ordered, promote the main object of the school and educate most fruitfully the rising generation? I might perhaps put the question into the form, How and on what grounds should the schoolmaster form a judgment of school workshops? What should he require of them?

Now, he would have, I take it, to admit first of all that, indirectly, Manual Training serves the school in so far as it assists in producing and strengthening those moral qualities which it is the aim of the school to foster.

Who would deny that it is the earnest endeavour of the school to train up the young to industry? Well, that the workshop also does. We too think that, as idleness is the parent of all vices, so is industry the beginning of all virtues. Thus the school and we are pulling in the same direction, and a rope is stronger if its strands be doubled.

It would be wrong to suppose that the advocates of Manual Training imagine that the cultivation of diligence is their province only, and disparage the intellectual work of the school. The error has found utterance on many sides; it is, however, an error none the less. How often have we not protested that we would fain *add* bodily activity to mental exertion? And when we speak of our form of education as *education to work*, we are but using for shortness' sake a common mode of speech, just as *workman* or *worker* is constantly confined in usage to one engaged in bodily labour. People should not charge us with exaggeration, as if we counted ours the only work, but should blame the common misuse of terms. There can be no misunderstanding here in Germany, for our Association has proclaimed its meaning by adding to its title the words "for *boys'* manual work": it is *der Deutsche Verein für Knabenhandarbeit.* Whilst, then, we do not claim that working with the body is the sole means of training up a child to industry, it will be conceded us that it can co-operate in such training. Personally I am convinced that the overcoming of physical difficulties is, in the first instance, an easier and more natural discipline in accustoming a child to exert its powers than any to be found in pure brain-work; for in body-work we can put before the worker a definite, palpable, and desirable end. However, gentlemen, you need not go with me so far as that. I only ask you to admit that a well-ordered workshop may be a nursery of youthful industry.

Our wish is to combine bodily activity with the intellectual work of the school. Thus it is not here merely a question of strengthening the action of the school, as in the school one subject strengthens and intensifies the action of another; but in the workshop we seize the matter from another side, we apply other means and strike into new paths. Now, when two straight lines intersect in space, they mark the point common to them both clearly and definitely enough. Even so have the workshop and the school, starting from opposite quarters, one clear, common mark of concentration.

The school must, of necessity, leave a large part of its industrial training to the home. The tasks are, indeed, set in school, but done at home. It is true that the master can encourage the diligent and chide the slothful. But in the workshop all is done under the teacher's eyes; there the incentive of emulation is visibly operative; the slow worker stands by his brisker comrade and learns to imitate him; the teacher has no need to drive, the work itself is impulse enough. The fruits of industry lie here in view of all, and the sight is more full of meaning and more persuasive than any words. Often we see engendered in the workshop downright enthusiasm for work. And the lessons of the value of time and the blessings of industry once implanted, are fruitful in every field of life.

This education springing directly from the matter in hand, this education by the actual, is, as I believe, of great pedagogic worth. The attitude of the teacher becomes changed. He does not require his pupils to do what is beyond them, but gives them welcome hints; he counsels and explains, but does not compel. The boy ends by seeing with his master's eyes, by himself consciously working at self-education—and that he should do this is the goal of our desires.

It has, perhaps with justice, been objected to school savings' banks, that, praiseworthy as their objects are, they are nevertheless failures, because, strictly speaking, it is only the parents that are saving; the children can as yet earn nothing, and ought not to earn anything; they have no savings to lay by. For my part, I leave the question undecided. But the tendency to save, the spirit of economy, so valuable in the social life of our people, can be cultivated in the school workshop in a very simple and practical manner.

If a net for a cube or a cardboard box is sketched out, care must be taken to utilise every inch of the cardboard. The wire ends and bits of brass tubing left over in making physical apparatus are preserved, to be afterwards used up when opportunity offers. Only those who work carefully are trusted with the better covering-paper, or the finer wood for carving; those who are wont to spoil material must be content with commoner kinds. The boy who cuts at a new board for each strip of wood required, and right into the bulk, is sent to the waste-heap, and has to seek there a piece to serve his purpose. In doing so, he learns to examine the different kinds of wood, to attend to the direction of the fibres, to distinguish knotty timber from clean, sound from rotten. The dealing economically with material, or, in one word, economy, is a thing a boy may easily learn along with other lessons in the workshop. Nay, his learning it is natural and inevitable. Workshops have the one great inducement to habits of saving, that they cannot dispense with them; the funds at their disposal are almost invariably very scanty.

It is even so with the training to neatness, order, minute accuracy. The school inculcates all these habits, but so does the workshop,—I might almost say, the latter in particular. The master requires the room, exercise-books, and books proper to be kept in order; he rejects dirty work, and has it done again; he exacts clear, logical thought and apposite expression. All this, constantly enforced and practised, must obviously have educative effect. But school instruction is necessarily class instruction; only one at a time can be questioned, and the sluggish-minded boy is but too prone to give himself a rest. The tasks in the workshop, on the contrary, are absolutely individual performances. Here a loose thinker cannot have the thinking done for him by means of a comrade's answers to the teacher's questions; nor can any hide his own sloth behind another's zeal. The work lies before the boy, and he must put forth his strength to do it. *Selbst ist der Mann* is the motto in every good workshop. In it, again, appears what we may call unintentional education by means of the actual. If the smartly-covered box is seized with dirty fingers, it is ruined; the master has no need to waste his words, the spoilt work speaks for itself, and eloquently. All those engaged in the practice of Manual Training know how carefully children guard against soiling the presents the recipients of which are already determined, and into which they have worked their heart's affection. Moreover, manual work requires strict accuracy. If the boards for a knife-box are not planed to a true right angle, the work is all askew. If dovetails are not fitted with minute care into their beds, they do not close properly. Just as good work brings honour to the master, so does idle botching bring blame to him who cannot teach himself to make his work accurate, to do everything with minute precision. I gather what I have said into the proposition—

Manual Training promotes the educational work of the school, by helping to train the pupils of the school to industry and economy, to neatness, order, and accuracy.

But it is not only in establishing a basis for these moral qualities that the workshop aids the school, the ends of instruction are also furthered by the workshop.

That the school workshop, intensifying the influence of Writing and Drawing, exercises to good purpose hand, eye, and sense of form, has often been maintained. We only touch on the question now to show that the work of the school is continued in the workshop, that both stand on the same pedagogic ground. But here again it is plain that not merely is the path opened by the school pursued by the workshop, but that both attack the same problem from opposite points of view. In Writing and Drawing, the tool—if the light pen or pencil can be called a tool—is guided over a surface by the hand, whilst the lower part of the arm rests on a supporting plane; the forms traced are not figures in space, but are confined to the two dimensions of the plane. In manual work, on the other hand, the tool is directed, in obedience to the mind, by both hand and arm; it fashions solids; all the three dimensions of space are at its service. I would indeed maintain that the making of solids is more natural to children than Drawing. Before ever they touch a pencil, they are given to building and moulding real objects. Drawings are abstractions: they abstract, as it were, the qualities of the solid to represent them on a plane; thus the psychologic and pedagogic order of progression is from Moulding to Drawing, and not from Drawing to Moulding. At a later stage Drawing and manual work go hand in hand. Still more important is the difference that in Drawing we are mainly concerned with shape, in practical work the material must also be considered; we must make ourselves acquainted with the properties of the substance we are to manipulate. Drawing develops mainly a sense of form, and, in a subordinate degree, a sense of colour; practical work requires constant study of the effect of form, colour, and material in producing a harmonious whole.

Again, the workshop deserves well of the school, by cultivating that habit of close observation which is of the greatest importance for all *Realien* in the school. The boy in the workshop cannot help observing. He who in driving in a nail lets his attention wander, hits himself on the fingers. Inadvertence when cutting paper is rewarded with cut hands. In planing, the workman must observe how the tree grew, how the fibres run, or he cannot obtain a smooth surface. If in metal-work he is required to make a straight handle or to bend a circular ring, he must look to it that the brittle metal is forced into the true shape that is proposed. If the Segner's water-wheel or rotation apparatus does not revolve, the cause of the failure must be discovered by due inference from observed facts. In short, in the workshop the boy is required at every step to exercise his powers of observation, and the work itself compels him to form conclusions from the results observed.

In like manner, the Arithmetic and Geometry lessons of the school are assisted by the workshop, which compels children to be constantly dealing with number and magnitude until they are familiarised therewith. Try an experiment: Ask a youth who has been some six or eight years at a higher school to show you the length of 60 cm., to guess the number of paces in a road, or the height of a tower. The result will surprise you. He will have formulæ enough in his head, be able to solve equations of the third degree; but he has never really mastered those measures on which so much of the economic life of his nation depends. In Geography, the children even in National schools work at the heights of mountains and the areas of countries without employing any of their faculties except—memory. Similarly with Evolution and Involution, fifth-form boys can extract roots or find powers, they cannot conceive the figure that will be obtained from a net. All is theory, there is no practical application. Now, in the workshop the foot-rule or metre-rule is the most important tool. Measuring and comparing, dividing and multiplying, are operations to be performed as a matter of course; without them no work can possibly be done. The ruler, the try-square, and the compasses are in constant use; the measuring of the size of angles, the calculation of areas for various regular figures, is inevitably necessary in the workshop; and above all, the actual seeing with the eyes is trained, the knowledge of three-dimensioned space cultivated. Perhaps it would be productive of good if we caused theory to be deduced from practice of this kind, instead of giving children only the theory and never allowing it to be practically applied. Pestalozzi, still our great master in pedagogics, says on this matter: "Man must not merely learn first and then do; but seek to learn by what he does." But time forbids me to enlarge upon the subject. I only maintain that the workshop, necessitating as it does constant dealing with number and magnitude, renders effective assistance to the school, and supplies a valuable basis of experience for the teaching of Arithmetic and Geometry.

Lastly, Manual Training acts, in the same sense as Gymnastics, upon the development of physical strength and dexterity; and, in particular, the workshop is, like the gymnasium, a fostering-ground of strength of will. Our work compels the boy to overcome physical difficulties, calls forth his powers and develops them in the vanquishing of the successive obstacles that arise, until his high-strung energy finds happy relaxation in the attainment of his end—a concrete product of his toil. When some goal of desire is in view, boys are capable, as experience shows in every workshop, of steady perseverance and unflagging effort. Whilst Gymnastics require a brief and violent exercise of will-energy, Manual Work demands that that energy should be put forth for a longer time: one act of willing succeeds another, engendering constant and stubborn resolution. If we admit that strength of will can never be inspired by words, but must be developed by action, we can hardly refuse the rising generation an opportunity of actively exercising its powers. This opportunity is afforded in the workshop. There the boy learns to work towards a definite goal, and there he trains his will by effort constantly renewed. From these considerations I deduce the proposition—

Manual Training deepens the influence of the school in that—in the same sense but in another way—like Writing and Drawing, it educates eye and hand; like instruction in *Realien*, it intensifies the power of observation; like Arithmetic and Geometry, it teaches how to deal with number and magnitude; and like Gymnastics, it develops physical strength, dexterity, and power of will.

I have, I trust, demonstrated that well-ordered Manual Training is calculated to give effective assistance to the education and instruction which the school bestows.

But objection might be raised that if Manual Training only aims at ends already pursued by the school, it is superfluous: it can easily be replaced by ordinary school subjects if these are given room for development. It would only be justifiable if there were no equivalent instrument of education; it would only be entitled to legitimation if there were some particular educational problem which it and nothing else could solve. I will attempt to establish that such is the case.

The greater part of the theoretic teaching in our schools is concerned with the cultivation of the non-practical intelligence. I am far from saying that the school does not also impart to its pupils a certain capacity for *doing*; but the capacity so imparted has its roots in abstract knowledge. The boy remains apart from that capacity for doing which real life requires, a stranger to a very important department of modern civilised life, the department of *Technik*. He has been introduced to history, he has learnt the laws of nature, his moral and religious sense has been expanded; but he can form no conception of even the elementary relations of *Technik*, he has no understanding for the products of industrial art, and thus an important part of the life about him, of the life that he is destined to share, remains incomprehensible. For indeed *Technik* plays no mean part in the civilisation of the day, and will be of enhanced importance in the future.

This department of life remains almost wholly closed especially to children of the higher classes. Their lives are spent almost exclusively in the acquirement of theoretical knowledge. It is here that Manual Training steps into the gap, and affords an indispensable supplement to the present scheme of education. It reveals to the boy, as it were, a new plane of life. Things and relations before unknown are brought near to him, and, step by step, he gains new insight. This forming of the *practical* intelligence, this insight into the elements of *Technik*, this development of a sense for the real and actual, is peculiar to Manual Training, which thus contributes to general education what nothing else can supply. I am now entitled to lay down the proposition—

Manual Training supplements school instruction in that to theoretic knowledge it adds real experience, and in so doing assists the development of practical intelligence.

Upon the fact that Manual Training is able to serve the school directly by guiding the learner to make *Anschauungsmittel* and apparatus for himself in a simple way, I have no need to dwell at any length. The matter has often been treated in the literature of the subject, and I will only refer you to the writings of Barth and Niederley, Bruhns, Höhn, Kumpa, Scherer, Kunath, Kummer, Magnus, and Nöggerath. None of these authors make new claims; they only present in a new dress the demand of pedagogic Realism ever since the time of Comenius—that to *knowing* must be added *doing*. The facts speak for themselves. You are acquainted with *Anschauungsmittel* which boys have made. Need I attempt to show that these have been of service to theoretic teaching? That, I take it, is hardly necessary. Last autumn I was present at lessons in Geometry and Physics, given in National schools where such appliances had been made. I can assure you that the whole class followed the teaching with lively interest; every scholar could answer the searching questions of the teacher promptly and clearly. The boys were naturally acquainted with the qualities of angles, the propositions relating to triangles, and so forth; for they had come to know them all by experience, from the models which, with simple means, they had themselves produced. There are in Hessen training colleges the pupils of which construct their own apparatus for Physics. Do you not think, gentlemen, that a master who has learnt to make simple means of illustration will give better lessons than one who can but build his teaching on words? My opinion is that a dexterous teacher, who with scanty means can appeal to immediate perceptions, is a substitute for a whole collection of costly teaching appliances, nay, is superior thereto, for he can make his humble creations live. Say what one will, the highest aim of the training college is to enable its students to give simple practical instruction, based on immediate perceptions, to the sons of the people. Furthermore, we offer here a course from our Leipzig Seminary, which, based on elementary cardboard, wood, and metal work, and not abandoning the independence of its own methods, makes an endeavour to bring Manual Training by means of the tasks proposed into closest connection with school instruction. My drift again is that Manual Training can serve the school. And thus I put forward the thesis—

Manual Training serves the school directly, inasmuch as it presents the ideas treated there in the form of immediate perceptions, and guides the learner to make for himself in simple form the apparatus and appliances necessary for such immediate perceptions and for experimental purposes.

And now I am drawing to an end. Manual Training—educational handicraft, as it is sometimes called—is not intended to qualify the trained for industrial pursuits, but forms a part of the essential education of man. Schoolmasters, being from the nature of their vocation the representatives of practical education, cannot hold aloof from such topics as this; they must take a side. We wish, then, for our educational question the interest and sympathy of schoolmasters. None but they can undertake the formal and methodic development, and, if I may use the term, the fertilisation of this important means of education, which daily extends its powers. Schoolmasters have not to ask themselves whether there should be Manual Training or not. The demand is already there, and growing under our eyes. The only question is whether that demand is to be satisfied with or without the concurrence of the teaching body. In my judgment schoolmasters should lead the van. Trained as they have been, they should regard it as a duty and an honour to see that the pedagogic thought underlying our movement receives consideration, and that no material obstacles are placed in the way of the complete education of our children. They should abstain from importing into the discussion matters which are foreign to it, and judge the instrument which offers itself simply upon its merits. We should not agree with a doctor who pronounced his verdict on an approved remedy thus: "It is not suitable for *me* to use, and therefore shall not be employed." It is just as unbecoming for an educator of the people to reject from class prejudices or other motives a means of education which really benefits the taught. If our cause deserves to be opposed, let them oppose it with clear and definite arguments which may be admitted or controverted, not with calumnies such as we have seen in black and white—such, for instance, as the statement that Manual Training leads to theft and the desecration of the Sabbath. The wood used could not, we are told, be bought by the poor, and therefore would be stolen. And when would it be stolen? On Sundays, naturally, when people have most leisure. In serious matters we are entitled to ask that the judgment passed should be serious and based on knowledge.

We may perhaps compare with the progress of education that of army organisation. In the latter it has been found possible to preserve what is good without renouncing the benefits of what is new. At the siege of Paris balloons did good service; corps of balloonists were straightway formed, and to-day our soldiers practise ascents and descents, and make their voyages through the air as if these had always been. The marvellous development of our railways had for a consequence the formation of the *railway company*, and later, of the *railway regiment*. The telegraph has long been an auxiliary of the army; and no sooner did the bicycle show its fitness for conveying intelligence than it was recognised by the Administration and embodied in the army organism. Is the thing serviceable to our country? is the only question. But he who in educational concerns is in advance of the general thought, must be content to suffer the martyrdom in store for heretics. We, in our case, must at least submit to have our colleagues say that we lead the children whom we love astray to theft and Sabbath-breaking.

But if our opponents disown education to work, they must be consistent; they must make their peace with the spirits of all the great men whose names adorn the history of pedagogics; of Amos Comenius and of Locke, of Rousseau and of Pestalozzi, of August Hermann Francke and of Salzmann, of Fröbel and of Herbart—they must say that these too erred. For all these and many others fully recognised the importance of Manual Training, and incorporated it in their schemes of education. Now, it is not enough to honour our great masters in word; we must do the deeds they bade us do.

Moreover, we demand from our antagonists proofs that the system of education now in vogue attains its end—the harmonious development of all the powers of man. From what we see, we are not convinced that that end is attained; on the contrary, we hold that education now is one-sided, and therefore needs to be supplemented. We claim the right to struggle towards the high ideal we have set before us. We regard bodily work in organic connection with intellectual activity as a means to the complete and harmonious education of the child, and would enlist it in the service of mankind. This and none other is our aim.

It only remains to offer you, gentlemen, my sincerest thanks for your courteous attention.

II

MANUAL TRAINING APPLIED IN THE SCHOOL: A SERIES OF COURSES TO ILLUSTRATE ITS APPLICATION.

It is a striking and far-reaching difference between the French system of Manual Training, so energetically developed, and that in favour with the Germanic races, the Swedes, Danes, English, Austrians, Swiss, and Germans, that the former encourages nothing but abstract studies, as it were, of *Technik*, exercises which have no other end than to teach the learner the use of tools. Among the Germanic nations, on the contrary, Manual Training teaches *Technik* from the construction of real objects; importance is attached to setting the boy to make some useful article taken from the sphere of his own interests.

Whatever one may think of this difference of opinion between, as one might almost say, the Romance and Germanic peoples, we must concede to the French that their mere exercises defend them against the opposition of the artisan who fears the competition of the products of the school workshop with his own. If the cutting-boards, after the boy has practised the use of the knife upon them, are planed smooth to be used for new exercises—if the clay, after receiving from the hand of the worker the desired form, is again bulked—there is naturally no need to fear that the things made will be sold for a price.

But is there no way to obtain the same result without rejecting the clear wish of the boy to produce something distinct, complete, usable for some given purpose? Yes, there is such a way. We have only to derive the tasks for manual work from the theoretic teaching of the school. If a boy constructs an *Anschauungimittel* for the celebrated theorem of Pythagoras (Euclid I. 47), or makes a simple apparatus to show the expansion of various metals under the influence of heat, artisans can no more fear competition than if his work were confined to the barest exercises. Moreover, tasks suggested by school instruction would have the great advantage of assisting to remove the prejudice entertained by many teachers against Manual Training. Often at exhibitions of boys' work we hear the judgment expressed that the domestic utensils shown are indeed useful and good, but have nothing whatever to do with the school; that the latter has more ideal aims, and must only concern itself with general education. Those who speak thus are not aware that Manual Training also has general education in view. They see the simple work, the finished object, but not the will tension it has called forth, nor the sustained activity of the boys' muscles and senses, nor the experience he has accumulated in making it. They regard the product of the work, and not the work itself. But if we show them, instead of objects for household-use, simple physical apparatus or *Anschauungsmittel* for mathematical or geographical instruction, made in school workshops, their interest for our cause is won, for such things assuredly belong to the school. They thus become disposed to sanction a subject which helps other subjects; they approve when they see children practically represent what has been learnt theoretically in the Natural History or Geography or Physics lesson.

An attempt has been made in the following pages, with the idea of bringing Manual Training to the notice of teachers and pupils of higher schools, to arrange a systematic course of work illustrative of the teaching of the classroom. We are not without hope that it will meet with a kindly welcome.

It must not, however, be supposed that in entering on this new path we are turning our backs on the ideas we have hitherto upheld. That is by no means the case. On the one hand, Manual Training will maintain its position, nay rather, increase its influence, if wider circles be made acquainted with its value; and, moreover, hand and eye will be trained and a knowledge of *Technik* conveyed by the making of apparatus no less than by the old tasks. We seek the same goal as before, but in a somewhat different way. The object on which the boy exercises his strength is not the sole end aimed at; on the contrary, in regard thereto we gladly accommodate ourselves to circumstances. What we wish is that the boy should experience the full blessing which the active employment of his powers can bring. We see no reason why we should not press manual work into the service of the school in quarters where the making of articles for everyday use has been regarded with contempt, just as with garden-keeping and simple work at the cooper's bench we have adapted ourselves to the requirements of country life. Our desire is to introduce a practical element into the education of boys, to give their impulse towards activity free play. Thus the principle of practical activity is the essential consideration; the principle may be carried out in different ways. Just as white light is broken in the spectrum into various colours, so may one educational idea present itself in many forms of application.

We by no means maintain that our pedagogic position is a new one. It is an old wish of pedagogues that to *knowing* should be added *doing*. Nor have attempts to realise the wish been wanting. I have endeavoured elsewhere[1] to show in detail how progress from observation to activity has affected our whole system of modern education, from the universities with their laboratories, their schools of pathology, hygiene, and so forth, down to the Kindergarten with its numerous practical occupations. Work at the university no longer centres in note-taking at lectures, but in productive employment in scientific institutions of all sorts, where students learn not by hearing but by their own activity. And what happens in the world of science is reflected in the school. Alike in higher and National schools the principle of learning by doing is forcing an entrance. In the teaching of Geography and Mathematics, of Physics and Natural History, there is a tendency to pursue the intuitive method, as it has been called, of Pestalozzi. The two subjects most near akin to Manual Training, Drawing and Gymnastics, are inconceivable without the active participation of the child; Manual Training exists only to induce that participation, and is the clearest expression of the desire to cultivate it.

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[1] *Bericht über den X. deutschen Kongress für erziehliche Handarbeit zu Strassburg*, i.e. Görlitz, Ottomar Vierling, 1891, pp. 38 foll.

Leaving the general question of the self-activity of the child as an instrument for its education, we beg leave to say that the idea of enlisting practical activity in the service of theoretic instruction is also by no means new, but has been mooted by Blasche and Heusinger, Salzmann and Guts-Muths, by the Herbart and Ziller school, by Niederley and Barth, by Magnus, Kumpa, and Scherer. Our attempt, then, is far from being the first of the kind. It has, however, its peculiarities. First of all, we do not seek to evade technical difficulty. Our aim being to educate hand and eye, and to use the overcoming of physical obstacles in forming will-power, we refrain from choosing tasks which present no technical difficulties whatever. Striving to make each object in the simplest possible way, we do not court such difficulties, nor do we avoid them. Again, we do not select our tasks from any one subject of instruction, such, for instance, as Geometry, but take them where we find them; tasks from Mathematical Geography or Physics are just as welcome as those from Solid Geometry, Mensuration, or Algebra. Moreover, within the limits of the single subjects, it is not the order in which topics arise in theoretic instruction which determines the order in our course. Thus, in Physics, an illustration of Electricity or Optics may occur before one of Mechanics. Order for us is determined by the necessity of graduating technical difficulties. These must be presented in regular sequence without gaps. The boy must learn in due succession to handle simple tools, ruler and compasses, scissors and knife, plane and saw, hammer and pincers; learn to excute accurately the operations of cutting and sawing, planing and hammering, riveting and drilling. We do not, however, undertake to solve all the tasks which can be derived from any given subject. The time assigned to manual work is too brief for that. Our aim is rather to develop capacity than to make apparatus. If the practical sense is once awakened in the pupil, if he has once learnt to use eyes and hands, the products of his work are secondary considerations; they mean no more to us than do old notebooks of written essays to the teacher of German.

But if we do not seek to evade *Technik*, we are on our guard against seeking to adapt to our use all the technicalities of all the crafts. To do so would but lead to amateur botching. It is characteristic of our system that it does not aim at the finished products of industrial art, and, on the other hand, that it does not tolerate the mere bungling which results from superficial knowledge. It is true that we do not think that the manipulation of a single material, such, for instance, as wood, will afford an insight into the elements of practical work. The methods of joining different materials are various. Thus, wood is joined by housing, by groove and tongue, by dovetailing, by mortise and tenon; metal, by riveting, by screws, by soft or hard soldering. With every material the methods of treatment are different, and a knowledge of the methods of handling one cannot replace a knowledge of the methods required by another. Accordingly, whilst we do not seek to rival the achievements of the bookbinder, carpenter, and locksmith, we offer work—simple work—in paper, in cardboard, in pressed pulp, in wood, and in metal. For the sake of physical apparatus, we add the elementary manipulation of glass—bending it, drawing it out, and cutting it. It will be seen that our course of glass-work is not independent, but is subsidiary to other work.

Thus, what we have to give our readers is a systematic arrangement of the elements of Cardboard, Wood, and Metal Work into a scheme of Manual Training in the service of the school. Our practical work can, by the tasks it proposes, be organically connected with school instruction, and may therefore hope to enlist the sympathies of all schoolmasters in its support. But it does not, for all that, renounce the independence of its own methods; for that independence, the right of proceeding according to true pedagogic principle from the easy to the less easy, is as essential to its success as to that of every other form of teaching. Imagine for a moment Manual Training subordinated to other subjects. Physics, as the study of it advanced, would require the execution of work of varying degrees of difficulty, first hard work, then easy, and so on. Meanwhile Mathematics, Geography, and so forth, would interpose their tasks also in the order of *their* requirements. All sorts of materials would have to be employed. The boys would have many tools in their hands, but would learn to use none. Confronted with tasks that were too difficult, they would have recourse to outside help or be content with slovenly performance; or, finding the work too easy, they would lose the joy which comes from obstacles overcome. Both would be results to be deplored. Our whole system would be dislocated and our aim thwarted, that aim being the education of the child through work to work, to industry, to conscientiousness, perseverance, and vigorous exertion of will-power. The products of our instruction would be, not valuable qualities of character won, but rather a number of objects and *Anschauungsmittel* made as the necessities of the classroom should chance to demand them.

No, we can admit nothing but orderly progress step by step from the easy to the less easy; the methods of our discipline must retain their independence.

It must be confessed that, holding fast to this principle of orderly procedure, we did not find at every step an article for school use which would suit our purpose. Under such circumstances, the exercise seeming to us more important than the thing to which it is applied, we have not hesitated to take the matter of our work from daily life. Perhaps it will eventually be possible to obtain complete parallelism in the series of models proposed, so that at every step forward the teacher will have the option between something for use in the classroom and some ordinary household utensil. Even then it will be necessary to insist that the *ultima ratio* is not the object made. The true fruit of Manual Training is the power of observing and the experience acquired by the boy, the cultivation of a sense for realities, the conscious direction of the bodily and mental powers to a given end. As it is, the few examples we have given of work not immediately suggested by the school are so apparent, that, as soon as suitable objects from the classroom are discovered by which just as much can be learnt, the temporary substitutes may easily be discarded, and the equivalent school tasks inserted in their place. It is better to indicate in this way gaps which remain to be filled, than to conceal their existence and thus hinder them from being filled. Moreover, no harm is done if articles of utility occasionally appear in our courses, and bring the school into closer contact with practical life.

It is in the nature of the case that we have sometimes to do with tasks which consist of parts belonging to different kinds of work. We have naturally given the preference to such as involve the employment of only one material; but mixed tasks could not be altogether avoided. If the parts of a piece of apparatus belong to different divisions, each part is given the proper place in its own division, and the apparatus is not put together until all the parts have been completed. This is especially the case when there are certain parts which cannot be made without previous practice. If it be only a question of simple, technically unimportant matters, such as the filling of weights, the bending of wires for pulleys, etc., the work is done as the occasion for it arises.

The only respect, then, in which our courses of Cardboard, Wood, and Metal Work differ from those already in existence, is that we here select by far the greater number of our subjects from the domain of the theoretic teaching of the school. The order in which the work is presented depends, we repeat, solely on its technical difficulty. We have taken care that the more important tools shall be successively brought into requisition, so that skill in handling them may be by degrees acquired; and we have made it our aim that the most important of them should be used most frequently. We have, moreover, in compiling the courses, caused the various materials to appear according to the degree of difficulty with which they can be manipulated, and have introduced in due series the employment of the most important ones—paper, cardboard, blotting-paper, thick and thin pressed board, different kinds of soft and hard wood, various metals, such as brass, copper, tin, zinc, iron, steel, and these metals in various forms, such as thin and thick wire, tubing, plate, etc. By way of supplement, we add such forms of glass-working as are indispensable to the construction of many physical appliances. We have hesitated to go beyond this and to admit other materials, such as indiarubber, cork, etc., for fear of losing the sure ground of educational handicraft and sinking into dilettanteism. Confining ourselves to those materials which have hitherto proved serviceable for our purpose, we leave the rest to those who have already gained some skill by handling cardboard, wood, and metal.

The same reason—the fear of going too far—has led us to renounce, though unwillingly, an instrument of very great value in working wood and metal. We mean the lathe.

Not only would the admission of turning expand the limits of our subject unduly, but it would increase considerably the cost of an outfit. The consequence of thus dispensing with the lathe is that we also dispense with all work that involves turning, and, as in the case of the pulleys, adopt some simple method of obtaining its results.

As in other courses, so here, mere preliminary exercises have been made as few as possible, and *Technik* is to be acquired by the making of real things—in our case, apparatus for use in the school. Preliminary exercises have only been suggested where it was absolutely necessary, where, that is to say, their absence would have endangered the success of the work. Such exercises are the cutting and scratching[1] of board (cardboard, wood-pulp, pressed board, etc.), the joining of a corner by dovetails, etc. See pp. 38, 78, 86, 105.

Lastly, we have for the most part chosen *Anschauungsmittel* and apparatus which will work independently, without requiring some other appliance to set them in motion. Teachers and boys alike, it will be observed, are anxious, when their work is done, to see if it acts properly. When a Segner's water-wheel is made, the cylinder must straightway be filled with water, and it is only when the rotation duly ensues that the worker is convinced his task is really complete. And it is a fact that the smooth working of a piece of apparatus is the best test of the labour expended upon it. But the rule of giving only independent *Anschauungsmittel* and apparatus could not remain without exceptions, and in isolated cases, where methodic procedure rendered it necessary, we have been obliged to abandon the principle.

In sending forth this scheme of work in connection with school instruction, we are moved not only by the hope of extending the scope of Manual Training, but also by the wish to quicken interest in the teaching of the classroom.

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[1] "Scratching" is used for the removing of part of the thickness of board in order that it may bend freely. "Cut half through," or "use bone," are other terms employed in books on the subject.

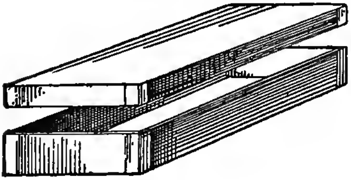
In our opinion, it is not enough to convey the laws of nature to the learner dogmatically; he must himself win by work a knowledge of them. And he may well do this by making for himself the necessary illustrative apparatus, be it only in an imperfect form; for thus his own experience will combine with his knowledge of science to produce a clearer and deeper insight into the marvels of nature. The true learner must be a doer, not a mere hearer of the word.

With this introduction we pass on to the practical part of our book.

A. CARDBOARD-WORK.

Introductory Note. Glue is the material chiefly employed as a binder; thicker for pressed pulp, thinner for paper. Glue alone must be used for glazed paper; on the other hand, with cylinder print and unbleached paper, especially for lining, paste or starch are also employed. To cover bottoms, we usually take unbleached paper of one colour; to line, cylinder print paper. In covering generally there is a large variety of papers to select from. The boards used are pulp boards, straw boards, and for very strong work, pressed board.

1. Preliminary exercises. Cutting-board, scratching-[1] board to make a bend.



2. Tool-box—uncovered. Material:—pulp-board; linen to bind the corners. Dimensions of the lower part:—25 × 7 × 4 cm.; dimensions of the lid, 25·4 × 7·4 × 2 cm. Order of procedure in making the box:—draw net,[2] scratch, cut out corners, close, and bind.

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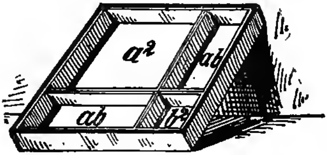
[1] See note, p. 37.

[2] "Plane projections, known technically as nets."—Science and Art Department, Circular 44.

3. Mineral box. An open box with a square base. Material:—thin pulp, black shagreen paper for covering, unbleached paper (brown) for lining and for the bottom. Dimensions:—base, 7·5 cm. square; height of box, 2·5 cm. Order:—draw net, scratch, cut out corners, close, cover, line, put on bottom of unbleached paper.

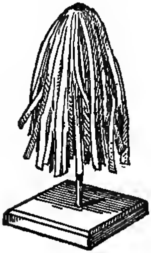
4. A group or set of mineral boxes. Technically considered, this is only a repetition of the work done in No. 3; hence the order of procedure is the same. The dimensions may be as follows:—Side of large square box, 10 cm. ($=a$); side of small square box, 5 cm. ($=b$); thus the dimensions of each of the oblong boxes will be 10 × 5 cm. ($=ab$); the height of all the boxes is 2 cm. The combining of the four boxes into one large square with a side of 15 cm. ($=a+b$) serves as an elucidation of the formula $(a+b)^2=a^2+2ab+b^2$, employed in extracting square roots, etc. The set of boxes is best enclosed in one large box, the dimensions of which will be obvious; it may be made somewhat higher than the rest, perhaps 2·3 cm.



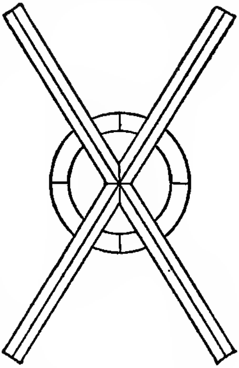
5. Balloon. This is a balloon made in strips, and is used to show that like electricities repel each other. Technically, the making of it is an exercise in paper-cutting. The length of the strips is immaterial. We employ variously coloured paper—blue, yellow, white, and red. The strips, being cut of equal length, are glued at top and bottom to two small cardboard discs covered with tinfoil. First, however, a thin wire is passed through the upper disc, bent into a hook at the top, and looped at the bottom to prevent it from getting out of place. If this hook be hung on the

conductor of the electric machine and the latter be put in motion, the strips, instead of hanging vertically downwards, belly out, because becoming laden with like electricity they repel each other.

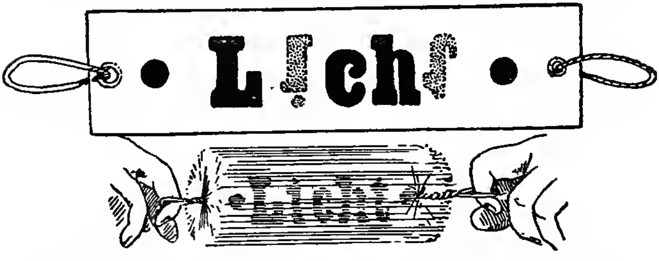
6. Paper tuft—to exhibit the same law of electricity as No. 5. The base is a square piece of board, each side being, say, 9 cm. The square is cut out, edged with calico, and covered above with dark marbled paper, underneath with brown unbleached paper. In the middle of the square a narrow cylinder rolled from cardboard is erected. In this cylinder we place a vertical brass wire about 17 cm. long, and at the top of the wire we fix a short cork, over which we glue enough strips of red and white tissue paper to form a thick, plume-like tuft. If we place the little apparatus on an insulating stand and then bring an electric current to bear, the strips bristle out in all directions, because, being charged with like electricity, they repel each other. To perform the experiment, we need only place the tuft on the conductor of an electric machine and set the latter in motion.



7. Illustration of the proposition that if two straight lines intersect one another, the vertically opposite angles are equal (Euclid I. 15). (After Kumpa, *Anschauung und Darstellung*, Model 21.) The technical value of this work depends on the skill it requires in the exact cutting and joining of paper; for not only must the upper angle be brought over and made to coincide with the lower, but the right-hand angle must also be made to coincide with the left-hand one. The construction is simple; but precision is necessary if the parts are to match as desired. The figure shown in the plate is cut from moderately thick board. The intersecting lines are 30 cm. long, the width of the strips is 1·5 cm. Our object is to divide the figure thus obtained by cuts, one exactly vertical, the other exactly horizontal, into four quarters, and then to unite these quarters again with linen hinges so that the coincidence of the vertically opposite angles may be exhibited at will. The pulp is not covered with coloured paper, but, as Kumpa recommends, is itself coloured. Very suitable for the purpose are the so-called enamel-paints, which are both opaque and give a glazed surface. In a model before us we have painted the two intersecting strips red, the circle which measures the angles blue. The enamel-paint is applied to the linen hinges as well as to the strips, so that the whole may look uniform.



8. A thaumatrope. This is a very simple piece of work in one plane. We have here practice in cutting pressed board rectangularly and in covering (without bordering) surfaces. First we cut a rectangle of moderately thick board and cover it with plain white or white surface paper (without bordering), so that the covering of the front overlaps on to the back, whilst that of the back covers the overlapping part pannel-wise. We then write on the front, leaving the proper interval, the letters *L* and *ch* (English boys may

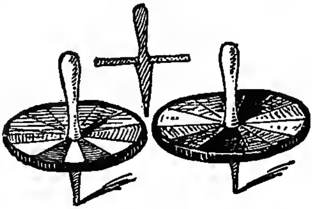


substitute *gh*), and on the back *i* and *t*. Instead of writing the letters we may buy printed letters, easily procured, and gum them on in their appropriate places. With a hollow punch we make holes to the right and left, near the shorter sides of the rectangle, fasten eyes with the nippers into these holes, draw white cords through the holes and knot them. The object is now finished. If we thrust the two forefingers through the loops formed by the cords, and twist the latter tight by turning the strip of board round, we then, on freeing the strip and drawing out the strings, cause the latter to revolve quickly, and to exhibit to the eye, owing to the duration of impressions of light on the retina, the complete word *Licht* (*Light*). Other words may be used for similar optical experiments.

9. Strips for the apparatus to exhibit the law of mechanical work. (See Bench-Work, No. 9.) Dimensions:—40 × 9 cm. Order:—cut board to measure, edge with calico, cover front with white, back with unbleached paper. Technically new is the cutting and glueing of a large surface, and the edging.

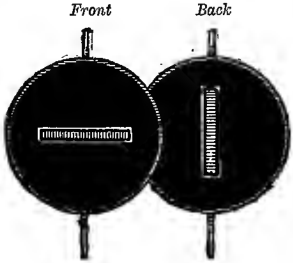
10. Slate with pencil-holder. Material:—pulp-board; calico for border and for the pencil-holder; slate-paper. Dimensions:—18 × 12·5 cm. Cut paper, border, make pencil-holder. The latter must be left for some time to dry. In the meantime cover the board with slate-paper; border, 2 mm. Fasten on pencil-holder, glueing it behind. Fix ring in the middle to suspend the slate. Practice in board-cutting and bordering. Technically new is the making of the pencil-holder and the dealing with slate-paper.

11. Organ pipes—open and closed. A perfect major chord is obtained from four open tubes, 30 cm., 24 cm., 20 cm., and 15 cm. in length. To make them, we take strips of stout paper or very thin cardboard, 7 to 10 cm. broad, and of the lengths already stated. These we roll round a cylindrical rod, and glue the long edges together. To produce a chord by means of closed pipes, we make the tubes 19 cm., 15·4 cm., 13 cm., and 10 cm.; thus, as a disc of cork 1 cm. thick is inserted in each, the true lengths will be 1 cm. less than those given. The process of making is the same as in the case of open pipes. Technically new is the making of cylindrical forms and the employment of very thin cardboard.

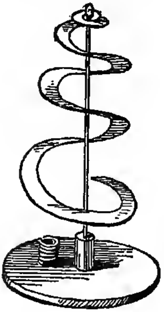


12. Top—to show the secondary colours as produced by rapid rotation (violet from blue and red, orange from red and yellow, etc.), the effect being owing to the duration of the impression of light. Several discs of moderately thick board, 9·5 cm. in diameter, are carefully rounded with the circle-cutter, and glued one on the other to the thickness of 4 or 5 mm. To strengthen still further, we glue another small disc of cardboard in the middle. After this, the large disc is edged with calico, covered on the upper side with paper of one colour, *e.g.* blue. On the blue paper are glued at equal intervals sectors of red. The lower side is covered with unbleached paper. A hole is punched in the middle with the hollow punch, and the spindle of the top (best obtained from a turner) inserted in it. Technically, the exact cutting of small circular discs and the careful attachment of the sectors present some difficulty.

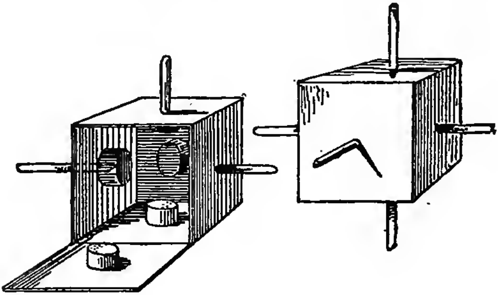
13. Disc thaumatrope. Two pulp-board discs of 12 cm. diameter are glued together; between them is fixed along a diameter a steel needle. Edge the double disc, cover both surfaces with black paper. Then fix strips of red glazed paper in the middle, the one on the front horizontally, the one on the back vertically. To make the red strips stand out better, fine lines are drawn round them with opaque white. If the needles be made to turn quickly between the fingers, the two strips are, owing to the duration of the impression of light, seen united into a cross. — Practice in disc cutting; careful execution required.



14. The dancing snake. A well-known toy showing the ascensional power of heated air. The foot is a round disc of board, about 8·5 cm. in diameter, bordered, covered, and furnished with a bottom in the usual manner. In the middle of this disc is a cardboard socket to hold the needle which supports the snake; a second socket near the first is for the candle. In the middle of the coil make a dint with a blunt point, or else glue there a very small ring of cardboard, and fix the coil thus on to the top of the needle; its own weight will cause it to assume a spiral, snake-like form.—Repetition of previous exercises; making of sockets; careful cutting of spiral with scissors.

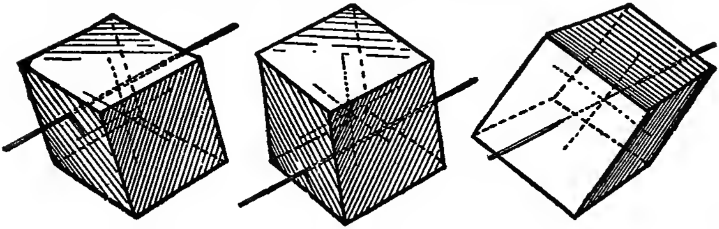


15. Cube to exhibit the three dimensions. (After Kumpa, *Anschauung und Darstellung*, Model 1.) The first closed solid in our course. The edge of the cube may be 6 cm. Draw the net in the usual way; cut out; scratch edge lines; find the points where the diagonals of each square intersect each other; and at these points, on what will afterwards be the inside of the cube, glue small corks (see drawing to left) to receive the wood needles. These needles serve to represent axes. When all is ready, close the cube and insert the needles (see drawing to right). Paint all over, needles included, with enamel-paint, as in No. 7.



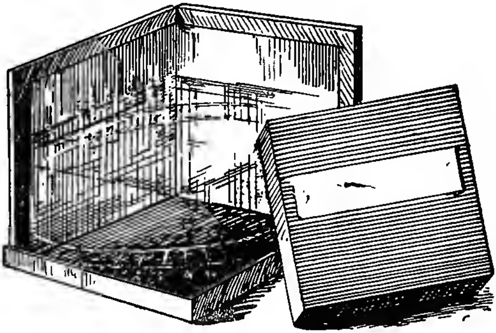
16. Cubic decimetre. A cube open at top with an edge of exactly 1 dm. Careful work necessary. Draw the net, cut out, scratch folding lines, cut out corners, line bottom with silver paper, close, cover, line sides with silver paper.

17. The three kinds of equilibrium. To show these we take three carefully-made cubes (edge of each, 6 cm.) of white cardboard. It is advisable, in order that our work may be a success, and that the centre of gravity may not be removed from the middle point, to cut out the nets of the cubes completely, and not to leave lappets for glueing purposes. When the three nets thus cut out have been



carefully scratched and bent, we join the edges by means of strips of red paper—that is, we edge or border the cube. To preserve the centre of gravity, this bordering must, of course, be on all the edges, the scratched ones included. Before closing the cubes we find on every two opposite sides the intersection of the diagonals. In the cube which is to represent stable equilibrium we bore with the awl holes *above* the middle point, *i.e.* the centre of gravity; in that which is to show unstable equilibrium, *below* the middle point. If, lastly, we bore through the middle point, the cube so treated serves to exhibit neutral equilibrium. The direction of the holes bored is shown in the drawing. When the cubes are completed, white horn needles are thrust through the holes, and if the needles be held at both ends, the three kinds of equilibrium may be experimentally illustrated. The work involves no great difficulty technically, but requires careful execution.

18. Corner mirror. (See Glass-Work, No. 3.) Square box with lid (size of square, 14·5 cm.; height of bottom, 1 cm.; of lid, 6 mm.), both covered with dark shagreen paper



and lined with smooth black paper. In this is placed what we have termed the corner mirror, *i.e.* two rectangular mirrors joined together by a calico hinge, so that they can be set in any corner or closed like a book. The two mirrors are first, to protect the silvering, backed with boards of the same size as themselves. We then lay them together and join two edges with a hinge of calico. Afterwards the corner mirror is edged and backed with calico of the same colour. The low cover serves to set up the mirror. It is useful to draw on the square bottom with opaque white a quadrant, and to mark the angles 72°, 60°, $51\frac{3}{7}$°, 45°, 40°, 36°, and 30°. If we hold an object between the mirrors set up in the corner, there are seen for an angle of 60°, the reflection being threefold, five images; for an angle of 45°, the reflection being fourfold, seven images.[1] Technically new is the handling of glass in bordering and covering it; also, the making of the hinge.

19. String telephone. Two cylinders, 8 cm. long and 6 cm. wide, are tightly covered at one end with parchment-paper, bladder, or caoutchouc. The two mouthpieces are covered and lined with simple material. The vibrating membrane is pierced in the middle, but to prevent it splitting a small disc of leather or stout paper is first glued on the inside, over the part to be pierced. A string is stretched between the two mouthpieces and fastened with a knot at either end, the knots being drawn into the mouthpieces so as to lie on the vibrating membrane. The telephone thus finished is available over considerable distances. Technically new is the covering and lining of short cylinders, as also the making of the hinge for the mirrors.

20. Double cylinder for the Differentialrolle.[2] (See

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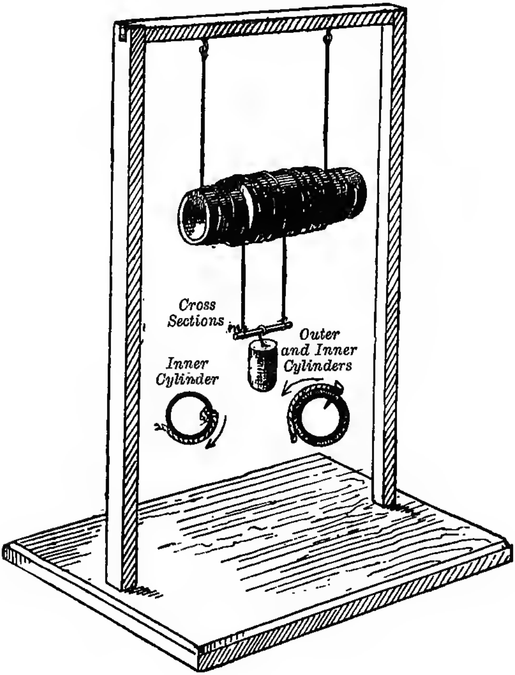
[1] See Weinhold, p. 433, Eng. translation.

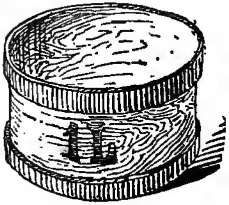
[2] The meaning of the name will be obvious from what follows. See Weinhold, p. 102, Eng. translation.

Bench-Work, No. 22; Metal-Work, No. 24.) This apparatus serves to show a principle involved in the action of simple machines. The roller is to be kept in equilibrium by the weight hanging on the small cross-bar underneath. Whatever multiple the distance travelled by the roller is of the distance travelled by the cross-bar, the same multiple must the weight on the cross-bar be of the weight of the roller. Distance and weight are, of course, here used for the number of units of distance and weight. Order in which the work is done:—Over a round wooden shape, say 4·5 cm. in diameter, we roll the inner, longer cylinder, 16 cm. long.



The material used is blotting-paper. This cylinder is bordered, and its outside surface is covered. Repeated layers of blotting-paper rolled round the inner cylinder give us the shorter, outer cylinder, 5 mm. thick, 8 cm. long. We cover this with the same paper as the inner cylinder. Holes are pierced through the latter in the same relative position to the edge, and through these are drawn the strings (secured with knots on the inside) by which the roller is suspended. In like manner, in the same relative position to its edge, pins are thrust nearly up to their heads into the outer cylinder. To these pins are attached the strings, coiled in the *opposite* direction to that of the strings supporting the roller, which hold the small cross-bar.—The forward step here is the making and covering of larger cylinders.

21. Low litre-measure. Over a cylindrical wooden shape (say 10 cm. high and 12 cm. in diameter), furnished with a handle by which it may be held, we roll a cylinder of blotting-paper, first removing the sharp edges from the shorter sides of the strip. A bottom is cut from board, covered on the side which is to be within, and fixed in position. To make the projecting hoops at the top and bottom, we wrap strips of blotting-paper twice round the measure. Blotting-paper is also glued over the bottom, and the edges are trimmed round. The hoops are now dressed with calico, the cylinder is covered and lined with paper stained to imitate wood, the bottom is covered with similar paper, and lastly the capacity, 1 L., marked on the vessel. The height of the measure, which must contain 1 cubic decimetre (= 1000 cubic centimetres) is easily reckoned by giving r, the radius, its proper value in the formula

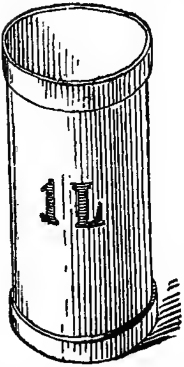


$$1000 = hr^2\pi;$$

$$i.e.\ h = \frac{1000}{r^2\pi}.$$

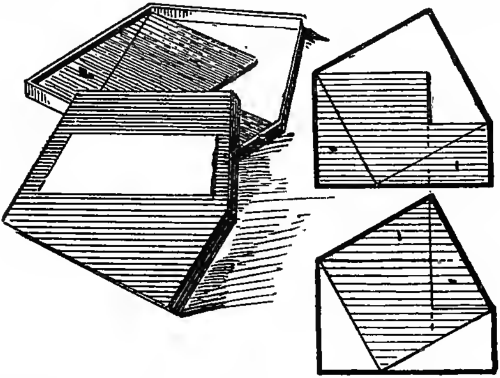
Technically, the exercise here is in lining wide cylinders, whilst practice in making round bodies is continued.

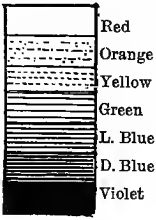
22. Tall litre-measure. The work is of the same kind as in No. 21; but the new dimensions make it more difficult.



The wooden cylindrical shape may be about 20 cm. high and 8·4 cm. in diameter. Here, as before, the exact height of the measure is to be worked out from the formula. The pupil must observe that the measure is too narrow and deep to be lined after it is closed. We therefore, taking blotting-paper enough to wrap twice round the shape, cover half of it on the side which is to be the inside. This is done before rolling. When the glue has dried a little (if we roll too soon, wrinkles are the result), we make the cylinder on the shape in the usual way. The procedure is exactly as in the previous exercise, but different material should be chosen; instead of wood-grained paper and calico, take silver paper.

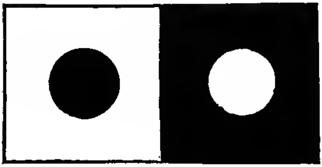
23. Pythagoras' proposition (Euclid I. 47). To exhibit the famous theorem of Pythagoras, we begin by fixing at pleasure the dimensions of the two sides containing the right angle. Let us suppose them to be 12·5 cm. and 5·5 cm. Starting from the dimensions, we first draw on our board the two squares side by side, as shown in our diagram. The line of division between the two squares is not cut. Dotted in our drawing, it is in the actual work marked with a white line. We next cut the outlines of the figure carefully; and also cut off the two right-angled triangles as indicated. Our second diagram shows how by simply building the triangles round, we arrive at the square of the hypotenuse. To hold the whole figure together, we make a flat box, which, as it must serve for both arrangements of the parts, has a pentagonal base. The dimensions are obtained from the figure to be enclosed. Its height is low—9 mm. The nets for box and lid are drawn, scratched, cut out, glued up. The two parts are covered (with marbled paper) and lined (with green unbleached paper); the bottom (of cylinder print paper) is then laid on. As the three pieces of board exhibiting the theorem would become inexact if covered, we colour them evenly with red enamel-paint. The two detached right-angled triangles are provided with small handles to enable them to be moved. Two tape loops, let into a slit in the upper surface, and glued on the under side, will serve the purpose. As the paint is laid on, the loops are also coloured. The large irregular-shaped piece which is not moved, is glued to the inside of the box. A label pasted on the lid describes the nature of the object. Technically new is the making of a box with irregular outline. The exact cutting of the pieces of board is of great importance.





24. The prismatic spectrum. A very simple object, but very useful for school instruction. The dimensions are immaterial; a suitable size for the classroom is obtained if each strip be 7 cm. deep and 20 cm. across. The spectrum is easily made; the only difficulty consists in the neat and exact mounting of *large* strips of paper. At the top, in the middle, a ring is let in, through which a tape passes and enables us to suspend the spectrum.

25. The effect of irradiation—that is, the seeming enlargement of bright surfaces against a dark ground[1] (due to the fact that the irritation of the retina spreads from the spot immediately struck by light to the adjoining parts)—can easily be illustrated by a very simple piece of work.



Cut from a moderately thick piece of board a rectangle, 42 × 20 cm., and divide into two squares by drawing a line down the middle. One square is covered with white surface, the other with black glazed paper. The covering-papers do not merely touch each other, but one overlaps the other so as to form a sharp line of division; moreover, they are cut a little large, and the edges turned over on to the back of the board. Afterwards this back is covered with brown unbleached paper, that the board may not warp.

Now find with the aid of the diagonals the middle points of the squares; with a radius of 3·5 cm. describe circles on black and white paper; cut these circles out with the scissors, and mount the black one on the white, the white one on the black ground. Punch a couple of holes with the hollow punch in the upper edge of the rectangle, fix eyes in the holes with the nippers, and you will be able to suspend the board at a suitable distance from the eye. The simple apparatus thus finished illustrates an important law of optics. The white circle on the black ground appears larger than the black one on the white, though both are just the same size. (Irradiation of the moon's crescent.

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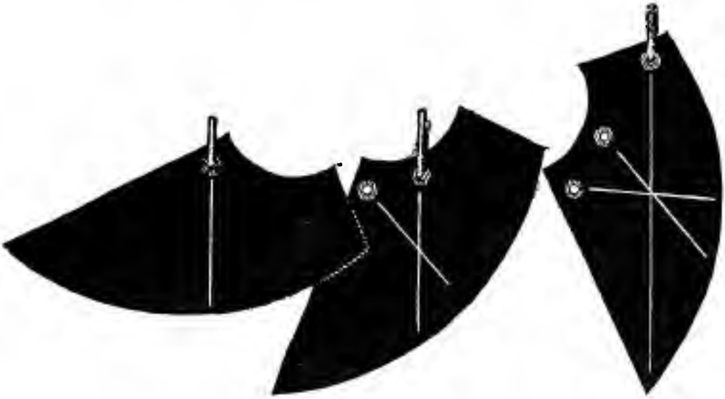
[1] So Plateau, but see Helmholtz.

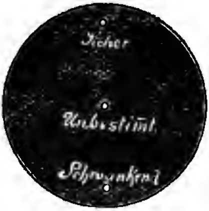
Optical illusions, due to the colour of the coverings, as to the size of the things covered. Example, black glove on one hand, white on the other.)

26. To find the centre of gravity of an irregular figure. Any irregular figure, such for instance as that in the drawing, which is bounded by straight lines and curves, is cut from moderately thick board. The size is immaterial; in the specimen model before us, the distance from the upper middle to the bottom point is 37 cm. The figure cut from board is edged with black calico, and covered with black paper. Then on the left and right upper points holes are punched and eyes fitted in. If we suspend the board first by a string through one of these holes and then by a string through the other, a plumb-line held at the points of suspension will give the two lines in which the centre of gravity is. The bottoms of these lines are marked, and the lines drawn with opaque white. The point of intersection is the centre of gravity. To check our work, we make a third hole with eye, and suspend the board at this point. If the work is correct, the line found by holding the plumb-line at this point will pass through the centre of gravity as

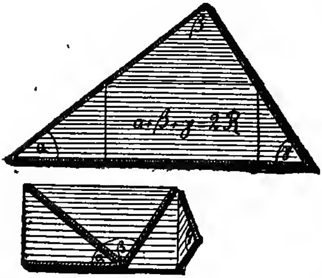


already found. The technical difficulty here consists in dealing with large surfaces and in bordering lines of various form.

27. Disc to exhibit the three kinds of equilibrium in the case of a surface. A disc of, say, 28 cm. in diameter is set out, cut, edged with black calico, and covered with black paper. On one of the diameters three points are determined—the centre of the circle and two points equally distant from the circumference. At these three points holes are punched and eyes inserted. Suspension of the disc at the middle point shows neutral, at the upper point stable, at the lower point unstable equilibrium. The object has been chosen on technical grounds, because here we have to cut a large disc carefully with the scissors and to border a circular edge.

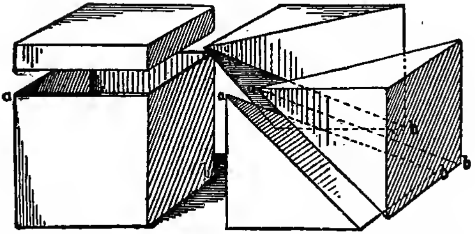


28. Illustration of the theorem: The three interior angles of any triangle are together equal to two right angles. (After Magnus, *Der praktische Lehrer*, p. 119.) Draw on cardboard any triangle you please—base, say 36 cm.; height, 23 cm. Let fall the perpendicular from the vertex to the base, bisect it, and draw through the point of bisection a straight line parallel to the base. From the points in which this parallel cuts the sides draw perpendiculars to the base. We have now found the pieces into which the triangle must be cut. To give increased strength, we draw another similar and equal triangle, treat as before, and cut out. The parts of the one triangle are glued



on to those of the other. We now by means of linen hinges unite the four double parts into the original triangle, border the whole with black, and cover neatly with red glazed paper. The upper drawing shows the triangle whose angles we are considering; the lower drawing exhibits the corners folded to make it plain that the three angles are equal to one straight angle (=180°), or two right angles.

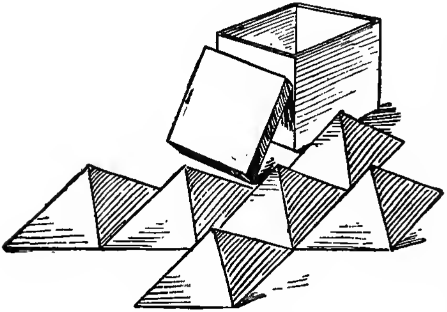
29. Division of the cube into three congruent pyramids. This is an interesting piece of work, taken from the field of Solid Geometry. At first sight it would seem an impossible task to resolve such a solid as the cube into three pyramids and these agreeing in every respect. But the task is easily effected if we remember that the line common to all the parts of the resolved solid is that from the left front top corner of the cube to left back bottom. This line is marked *a b* in our drawing, which shows the manner of cutting.



The technical execution causes no great difficulty; it requires only accurate drawing and neat glueing of the three pyramids when they have been carefully cut and the folding lines scratched. We take white cardboard, and draw three times the net of a pyramid, the base of which is a square of 7·5 cm. edge. The height of the pyramid is exactly the same; the length of its other edges follows from the dimensions given. The nets carefully drawn and lappets for glueing purposes planned, we proceed as usual to cut out, scratch folding lines, and glue together. The last-mentioned operation is done with the greatest neatness, the lappets lying inside, so that three clean, sharp-edged pyramids are obtained. It is better to border the edges with coloured paper, so that the cube, formed of the pyramids (see right-hand drawing), may stand out clearly. The pyramids made, they are enclosed in a well-fitting, cube-shaped box, with a simple lid (see drawing to left). The box is made in the usual way :—draw net, scratch, cut out, glue together, cover and line; write on lid the name of the object: Cube divided into three congruent pyramids.

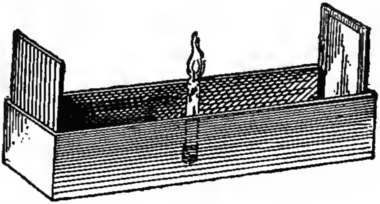
30. Cube cut from the middle point into six congruent pyramids with square bases. On each of the six square sides which contain the cube a pyramid is erected, so that the apex of each pyramid lies exactly in the middle point of the cube. The length of the edge of the cube may be taken at pleasure; let us suppose it 8 cm. The length of the edges of the pyramid may now be determined. If we call the edge of the cube k, and the edge of the pyramid, as it is also the radius of the circumscribed sphere, r, the length of the edge of the pyramid will be found from the formula—

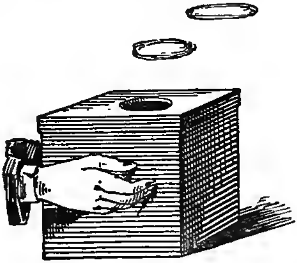
$$r = k\frac{\sqrt{3}}{2} = 0{\cdot}866k.$$



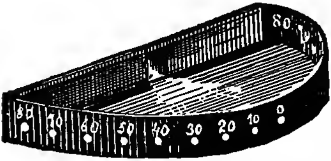
Thus the length of the edge of the cube being 8 cm., the edge of the pyramid is 0·866 × 8 cm. = 6·928 cm. With these dimensions we draw the net of the pyramid six times on white cardboard, leaving as before on the sides of the triangles the lappets necessary to close the pyramid. We then scratch the base lines, and cut the six nets out, and carefully glue together so that the lappets are on the inside. We have then only to join together the six pyramids in the way shown in the drawing. This is done by means of narrow strips of black linen, which mark the edges of the cube. The size of the cube determines the dimensions of the box with lid. This is made in the usual way. Cover with dark calico, and write on the lid with opaque white the description of the object: Cube cut from the middle point into six congruent pyramids with square bases.

31. Light echo. (See Glass-Work, No. 4.) Two parallel mirror surfaces which reflect—echo, as it were—a light burning between them. We have only to make a somewhat large box with lid, and to do some minor work. The box may be 28 × 9·3 × 4·5 cm., the lid of corresponding length and breadth, and 1·7 cm. high. Both are bordered, covered with marbled paper, and lined with black. The two mirrors (18 × 9 cm.) are backed with board, edged with linen, and then covered at the back with paper. To hold them upright, quadrangular pieces of board covered with black are glued to the bottom of the box across the two ends. Lastly, a socket of cardboard is made for the candle, and fastened to the bottom of the box.



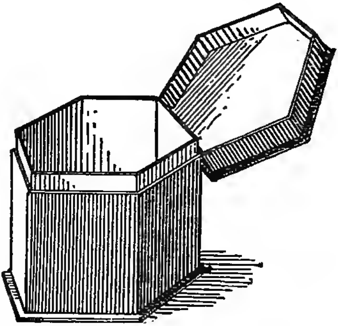


32. Box to produce vortex rings. (See Krieg, *Der praktische Experimental-Physiker*, pp. 71, 72.) This is a cube-shaped pasteboard box. Edge of cube, 18 cm.; diameter of hole in cover, 9 cm. The box is constructed in the usual way; but the surfaces are larger than in previous instances, and the cover must be carefully made to fit. Covering, dark brown marbled paper; lining, brown paper. To obtain the vortex rings we may use tobacco smoke; or, two pads of blotting-paper are prepared, upon one of which a small quantity of muriatic acid is poured, upon the other a similar quantity of strong aqua ammonia. The pads being laid in the box, fumes are produced consisting of chloride of ammonium floating in air. By tapping opposite sides of the box, we can expel the fumes in the form of rings from the circular hole in the cover of the box.



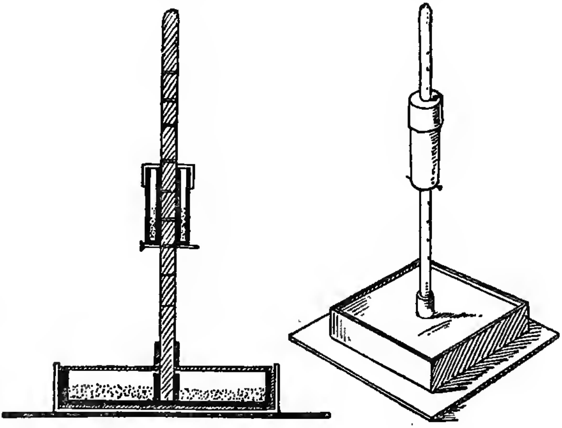
33. Illustration of the optical law that the angle of reflection of a ray of light is equal to the angle of incidence. (See Glass-Work, No. 6.) This is an apparatus, easy to make but very instructive, to exhibit the reflection of light. The base is a semicircular piece of stout board, the radius being, say, 22 cm. On the straight side of this base rises the perpendicular back, 44 cm. long, and, measured outside, 5·3 cm. high. The curved side is surrounded by a strip of thinner board of the same height. The three parts—base, back, and curved front—are joined together with strong glue, but not until the front has been graduated; at first they are only put together provisionally. Exactly in the middle of the back is let in a small mirror, from 2 to 2·5 cm. wide, and of the same height as the inside of the box (5 cm.). The stages in constructing the apparatus will be as follows:—First cut the back and the curved front and let the mirror into the former; then edge with calico (the curved front at first only at the top, at the bottom leave half the calico free); cover, and put the various parts provisionally together. The curved front is then divided into eighteen equal parts—these being 10° apart. The division in the middle, just opposite to the mirror, is marked 0°. To the left the divisions 10°, 20°, 30°, etc., are traced on the *outside* of the front; and at half the height of it, holes 1 to 1·5 cm. in diameter are pierced so that the lines of division exactly bisect the holes. To the right of the middle point marked 0°, the divisions 10°, 20°, 30,° etc., are traced on the *inside* of the front. When everything has been done which it would be too late to do after the box is put together, we proceed to join the parts. This is facilitated if the curved front overlaps the back, the overlapping ends being turned down. We next cover the parts still uncovered, and paper the bottom. If, the work having been carefully executed, the eye is applied to the aperture at the division 10° and turned on the mirror, the division 10° marked on the *inside* of the front will be seen; and so with 20°, 30°, etc. Thus this simple apparatus exhibits clearly the law of the reflection of rays of light. The construction requires accurate work; technical difficulties arise owing to the peculiar shape and to the necessity of joining the parts together.

34. Hexagonal box with neck, lid, and projecting edge on bottom and lid. The lid moves on a hinge; each side of the hexagon may be 8 cm., the total height of the box 15 cm., that of the lower part 12 cm., of the lid 3 cm. The hexagons for projecting bottom and lid must be somewhat larger. Order:—draw net of the side-walls, cut out, scratch, close, separate upper from lower part, draw patterns for (inner) top and bottom, cut out, cover bottom, fix top and bottom in position. The sides of the lower part of the box are coated once on



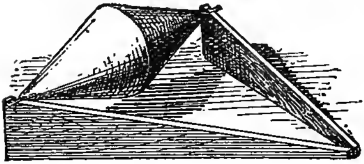
the inside with thin board, that the lid may afterwards have space to turn in. The edges of the lower part and of the lid are now bordered, hinges of calico attached inside and out. The neck is scratched, covered 2 cm. from top, and glued into box. The box is covered. The *projecting* top and bottom are made and glued on. Last of all, the whole is lined.

35. Equilibrium apparatus. (See Bench-Work, No. 4.) As the equilibrium of a body depends on the size of the supporting surface, on the height at which the centre of gravity lies, and on its own weight, an appliance to show the condition of equilibrium must be capable of alteration in these three respects. We suggest the following apparatus for the purpose. The work is entirely in board, except that a round upright, planed and filed (see Bench-Work, as above), is required to complete it. We first make a box with sliding-lid (side, 13 cm.; height, 3·5 cm.). The details of the construction may now be assumed to be known. The form of the box with sliding lid is chosen so that we can alter the weight at pleasure by putting iron filings or shot

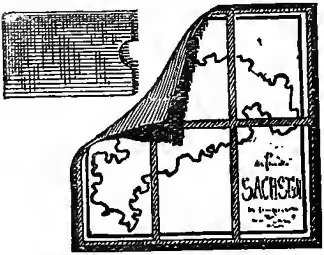


into it. Moreover, to be able to change the size of the supporting surface, we make a stand in which the whole box can be placed. This stand consists of a square piece of board (edge, 20 cm.), on which is glued an open box frame large enough to contain the box with sliding lid, and at least as high as it. We have now only to deal with the height of the centre of gravity. To raise or depress this at will, we have recourse to the following expedient. On a cylindrical wooden stick (2 cm. in diameter, 36 cm. long) there is a round box which can be moved up and down. The box has no neck, is in all 7 cm. high, and consists of a lower part and an overlapping lid. To enable us to move it and place shot in it, it is made like a reed, being bounded both on the inside and the outside by a cylinder. The diameter of the inner cylinder may be 2·3 cm., of the outer one, 4 cm. To allow us to fix the box at various points and so to alter the position of the centre of gravity, holes are pierced at equal intervals through the upright. We have still to indicate how the upright is connected with the box. This is done by means of a socket in the inner box, the socket being rather more than 2 cm. in diameter, and 3 cm. high. That the upright may stand firm before the socket is fixed in its place, a hole is bored in the sliding lid, and round this hole a second socket is made, as shown in the drawing. This second socket is of about the same height as the box, and of the same size as the first-mentioned socket. The task is one which implies a certain mastery of the processes of Cardboard-Work.

36. The double cone which runs uphill. This is a somewhat more difficult piece of work, but is not one beyond the capacity of boys. It supplies, moreover, a pretty example of the effect of gravity. The method of construction is given by Weinhold (*Vorschule,* pp. 82, 83) in his customary lucid style. The double cone is made in two parts with several layers of blotting-paper, wrapped over a suitable wooden shape. The edge of each cone may be 15 cm., the radius of the circular base of the cones 5 cm. Small triangular flaps should be left along the arc of one of the nets; these serve for attaching the two cones at their bases. The double cone, being thus made in the rough, is then covered with silver paper.—The rails are made of two pieces of board, 40 cm. in length, their height being 7 cm. at one end and 4·5 cm. at the other. The two lower ends of the boards are joined with a piece of linen glued over the edges, so that the boards form an acute angle with one another. The higher ends are connected either by a string of suitable length, or by a cross-piece of board, 28 × 7 cm., hollowed out in the middle so that the double cone can reach the end of the rails. The rails will stand still firmer if we fix them on a base (40×40 × 28 cm.). They are covered and lined with dark shagreen paper; the base, if used, is underlaid with unbleached paper.

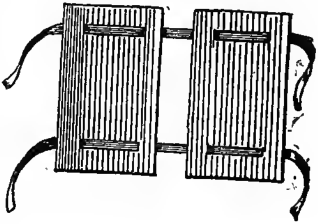


37. Mounting a map on linen and making case. The map to be mounted is carefully divided and cut into an appropriate number of parts (in our drawing, six). A piece of shirting large enough to receive the whole map and also to leave a margin round the edges is stretched tightly out on a board with tacks; the parts of the map are then carefully pasted on in rows, in such a way that the map can afterwards be easily folded together. When dry, the shirting is trimmed at the edges so that the angles are all true right angles. The case is made of blotting-paper. Draw net, cut out;

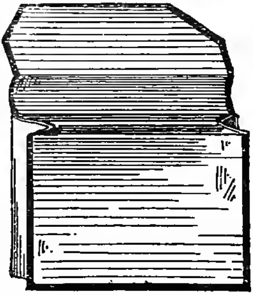


the folding lines are not, in the case of blotting-paper, scratched, but sharply creased; when the case is glued together, the projecting lappets must come on the inside. Cover case with calico.

38. **The Herbarium** is technically a simple object to make, and the only difficulty is caused by the large surfaces which have to be cut equal and covered. The two backs are cut from moderately thick board, 36 × 26 cm.; the eight corners are protected by linen tips; the outsides are covered with marbled paper, the insides lined with unbleached or cylinder print paper. Lastly, the slits for the ribbons are made in positions which will be understood from the drawing; the ribbons are drawn through, and a white label is pasted on the front to show the use for which the case is intended.

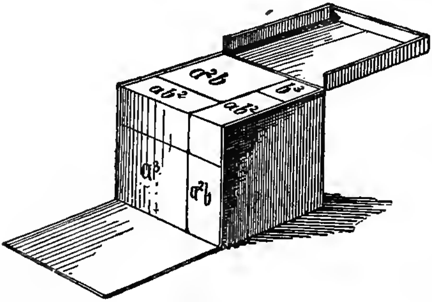


39. **Portfolio with pocket and flap.** We give this as an exercise in back-work and in the making of a pocket. The two sides of the portfolio are cut from moderately thick board to the dimensions 30 × 24 cm. The flap is also cut; its width is 9 cm.; the corners are cut away so that 4 cm. is removed from the shorter, 6 cm. from the longer side. The two backs, *i.e.* the covering pieces at top and bottom, are next made. Linen back, 6 × 32 cm. A strip of paper is cut, 2 × 30 cm., the linen back smeared with glue, the strip of paper and the two covers set on so that these are removed on right and left



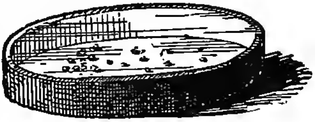
3 mm. from the paper strip. Cover with marbled paper. Before lining, there is a strip of linen, 5 × 29 cm., glued on the inside to the two backs. Lining: — The lining-paper is 2 mm. from the inner back, on the upper and lower edge 4 mm., and on the front edge 6 mm. The pocket is made separately, and glued in when finished. The material for it is thick white paper, covered with cylinder print paper. Then the fold is creased and glued into the pocket. The pocket is then ready for glueing into the portfolio.

40. Exhibition of the formula $(a+b)^3=a^3+3a^2b+3ab^2+b^3$. a^3 is represented by a cube the edge of which is, say, 8 cm. long, b^3 by one of 4 cm. edge. Three rectangular blocks are also made, the base of each being a^2, *i.e.* a square of 8 cm. side, and the height b, *i.e.* 4 cm. Three other parallelopipeds are added, the base of each being b^2, *i.e.* a square of 4 cm. side, and the height a, *i.e.* 8 cm. These solids are put together as the adjoining figure indicates, and form a cube whose edge is $a+b$, *i.e.* $8+4=12$ cm.; the cube is thus $(a+b)^3$. The construction is simple. The nets drawn, scratched, and cut, they are joined by means of the lappets, which must come inside. Cover with brown paper stained to imitate wood. The part of the formula each piece represents is written on it with opaque white. To combine them all into one large cube, we make a case, the construction of which is plain from the drawing. The case is edged with calico, and covered with the same paper as the solids. On the lid we write with



opaque white the formula the truth of which has been exhibited.

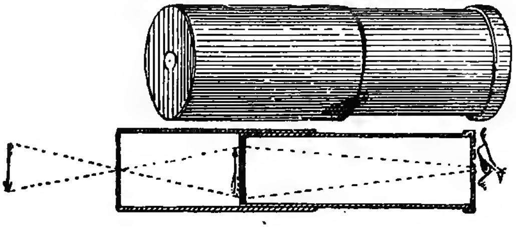
41. Electric toy. (See Glass-Work, No. 8.) A round cardboard box to illustrate the repulsion of like electricities. Diameter of the base, 18 cm.; height of side, 3·5 cm. The interior is coated with tinfoil; a round sheet of glass, 18 cm. in diameter, serves as a cover.

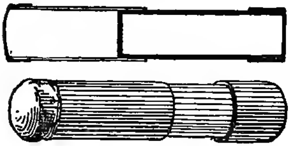


The construction is as follows:—The base is drawn and cut, the circular side or rim of the box is cut to a corresponding size and closed into a cylinder. Inside this cylinder another cylinder slightly narrower and lower, and made of thinner board, is glued so as to form a rest for the sheet of glass. Inside the box we put light solids, such as paper cuttings or lozenges or balls of pith. The glass cover is now put on, the box edged at top and bottom with calico, then covered, and a bottom of unbleached paper laid on.

If the glass is electrified by rubbing it with flannel or leather, the pith balls, etc., leap up to it, become charged with its electricity, and, as like electricities repel, are driven back again to the bottom of the box. Here the tinfoil carries off their electricity, and, being non-electric, they are again attracted to the glass, the process continuing as long as the latter remains electric.

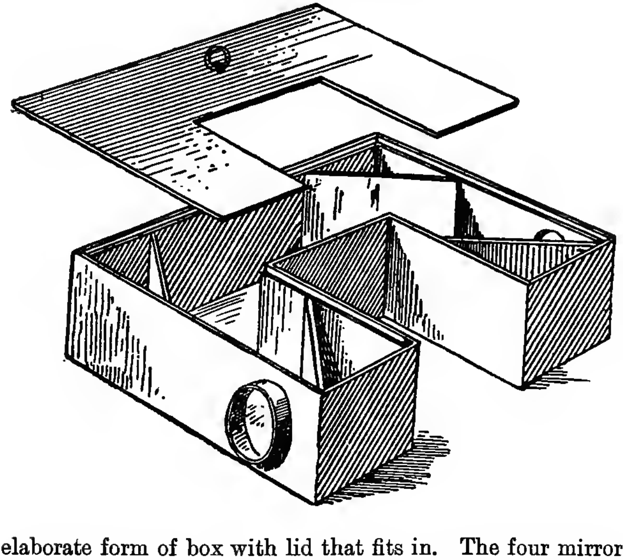
42. Camera clara. Two board cylinders, joined telescope-wise, the outer being open at one end, at the other closed in a particular way, whilst the inner one is closed at both ends. The total length may be 20 cm., the diameter 7·5 cm. The inner cylinder is closed on the inside with a disc of ground glass, with tracing-paper or with oiled writing-paper; on the outside is a round cover, in which a hole to look through is punched. A rim of board at the end of the cylinder enables us to close the camera into a compact whole. The larger outer cylinder is closed by a disc of board, in the middle of which a narrow (2 mm.) aperture is made. Bordering, covering, and lining follow as usual.—The apparatus exhibits the transmission of light in straight lines, as will be seen in the lower sketch. In experimenting, direct the camera directly towards the light, and thrust in or draw out the inner cylinder until it reaches the position in which we see in a reversed position the strongly illuminated objects at which the instrument is directed.



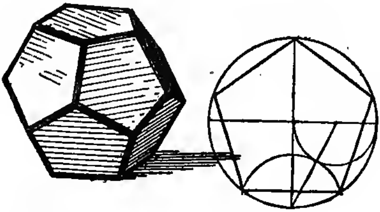


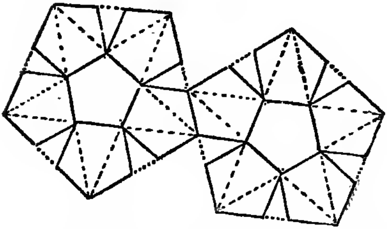
43. Apparatus for exhibiting the nature of air—to show the learner that the air of which he thinks so little is material. This is another cylindrical work which must be made so that the parts fit each other exactly. As in No. 42, there is a smaller cylinder fitting telescope-wise into a larger outer one. The upper drawing is a vertical section of the instrument shown in the lower. The length of the inner cylinder may be 18·5 cm., its diameter 5 cm. All cylinders are made by wrapping a few layers of blotting-paper about a shape. The outer cylinder may have a total length of 21 cm., a ring 5·5 cm. wide being subsequently detached from it and glued on to the lower end (in the drawing, the right-hand side) of the inner cylinder. The diameter of the outer cylinder may be 5·4 cm. The open (in drawing, at left) end of the outer cylinder has an indiarubber skin stretched over it, the edges overlapping the cylinder and being secured on to it with a strip (2 cm. wide) of calico strongly glued. The lining, rolling, putting in bottoms, bordering, and covering are all as before. In experimenting, the boy thrusts the well-fitting inner cylinder into the outer, and shows, by the swelling of the indiarubber skin, how the confined air works like solid matter.

44. Looking round the corner. (See Glass-Work, No. 5.) As our drawing shows, the task here is to make a more elaborate form of box with lid that fits in. The four mirrors set in the corners at angles of 45° with the sides are clearly represented. We need, besides, apertures at the entrance and exit of the apparatus, these apertures being enclosed with short cylinders. In accordance with the optical law that the angle of reflection of a ray of light is equal to the angle of incidence, we are able by this device literally to look round a corner.

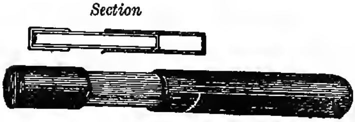


45. Dodecahedron. To have in our course an example of one of the regular polyhedrons treated of in Solid Geometry orCrystallography, we choose the dodecahedron, which is enclosed by twelve pentagonal surfaces. We take it for granted that the method of constructing a regular pentagon is known. (See Magnus, *Der praktische Lehrer*, p. 138.) Take the radius of the circle in which the pentagon is described as 5 cm., construct the pentagon, then the two groups of pentagons (as shown) joined along one side only. (See Magnus, p. 137.) Cutting out, scratching, closing, and bordering are all as usual. As material, use grey cardboard; for the borders marking the edges of the solid, red glazed paper.





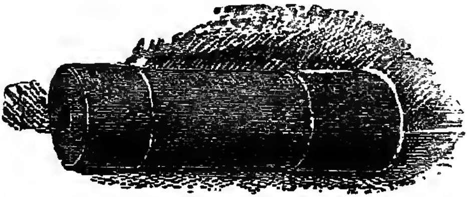
46. Pop-gun. Another exercise in the making of cylinders which must be exactly performed if the toy is to be usable. As an illustration of Physics, the pop-gun shows that not only does compressed air suddenly expanding, but also rarefied air suddenly compressed, produce a report.—The inner cylinder may be 19 cm. long and 3 cm. in diameter; it is closed at both ends by circular discs. The outer cylinder must fit closely about the inner one; it may have a total length



of 21 cm., 9 cm. of this being afterwards cut apart for the cover. The cylinders are, as in previous cases, lined before being rolled. The rest of the work is as usual. If it be well done, when the inner part is drawn out, a report is heard.

47. The kaleidoscope.[1] (See Glass-Work, No. 9.) The tube is of blotting-paper; it is covered with paper, and in the interior are glass discs.

About a well-turned cylindrical wooden roller, 20 cm. long and 5 cm. in diameter, blotting-paper is wrapped three times, and a cylinder 16·5 cm. is in this way made. The blotting-paper is lined, before the wrapping, with dead black paper. Whilst the cylinder is still on the roller, we lay smoothly round it a strip of newspaper, not less than 5 cm. wide. This strip is glued together, and can be removed at will. About this we wrap a cylinder 4·5 cm. long, lined with glazed white paper, but only consisting of two layers of blotting-paper. Removing this cylinder, we roll a second exactly like it. After the removal of this and also of the 16·5 cm. cylinder from the roller, two short cylinders, strictly speaking only rings, are to be made. One (*d*) is 5 cm., the other (*e*) is 8 cm.; both are of blotting-paper, three or four fold, lined with white. In one of the 4·5 cm. cylinders (*b*), the ring (*d*) is glued so as to be flush with the end; the other (*c*) receives a bottom of moderately thick board, lined with dead black. The board-work for the kaleidoscope is now finished. Next the covering begins.



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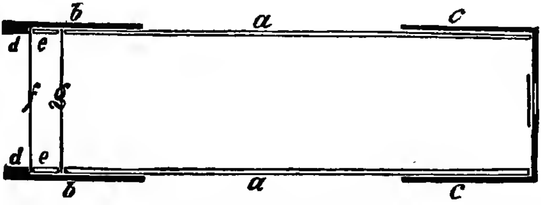
[1] After Emil Meyer, *Blätter für Knabenhandarbeit*, 1893, No. 8.

Both edges of the cylinders *b* and *c* are bordered with good gold paper—bright, not dull gold. After the bordering comes the covering proper. The best paper to use is leather paper—imitation calf, which wears well, and is even damp-proof. The cover of the cylinder *a* is turned in at both ends for about ¾ cm. The cover of the two shorter cylinders is cut so that at their two ends gold edges, 2 mm. wide, not more, are left exposed. The disc-shaped covering of the bottom of cylinder *c* also leaves a small gold margin free. As the cylinders *b* and *c* were rolled over a piece of newspaper afterwards removed, they will pass freely, but not too loosely, over the ends of cylinder *a*, in spite of the fact that the latter has been covered since it was first made.

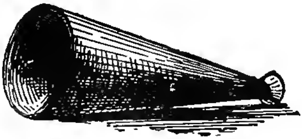


For the inside of the instrument we still need the glass discs, the mirrors, and the filling. The discs—one of clear, one of ground glass—are best cut by the glass-cutter with the mill. We can thus get the diameter true to the millimetre. The diameter is equal to that of the cylinder *a* (measured from outside to outside), and is thus about 5·2 cm. The disc of ground glass (*f*) is placed with the ground side outwards, in order that that side may not be scratched by the filling—that is, the scraps of glass, etc., which are to lie between *f* and *g*. Placed in the open cylinder *b*, the disc rests on the ring *d*, already glued in. The hoop *e* and the clear disc *g* are then to be laid above *f*. The outside case is now finished. The cylinder *c*, the eye-piece, is pierced with a 1 cm. punch so as to make an opening for the eye to look through.

The best mirrors for the kaleidoscope are those of black japan. To obtain a regular image we use three equally wide strips of glass free from flaws. These strips are 16 × 4 cm., and are covered evenly on one side with black japan. When the varnish is dry, the uncovered sides are carefully cleaned of perspiration, dust, or any of the varnish which has run over the edge. The unvarnished sides are turned inwards, and the three mirrors joined together so that the space between them is of the shape of a triangular prism. The edges of the mirrors are joined with dull black paper, the blackened side being inwards. The prism thus made must fit firmly in the cylinder. If it is not large enough to do so, wrap and glue newspaper about it until the desired size is obtained. Then, when the prism just fits in, apply strong glue to the edges and fix into the cylinder.

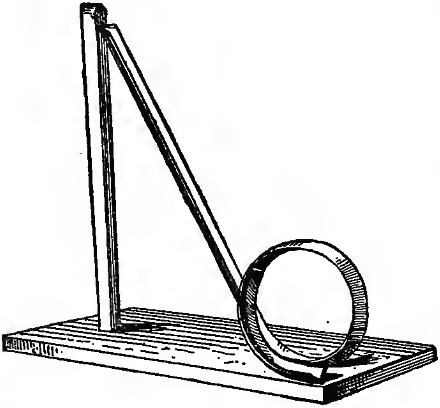
For the filling all sorts of small transparent objects are available. Best of all are small pieces of coloured glass varying in shape. The following are also suitable:—glass pearls, bugles, glass splinters, and particularly figures cut from gelatine with a 1 cm. punch.

In filling in, do not put too much between the discs; there must be room enough for the small bodies to tumble about. They will present the image of a regular star of ever-changing form.



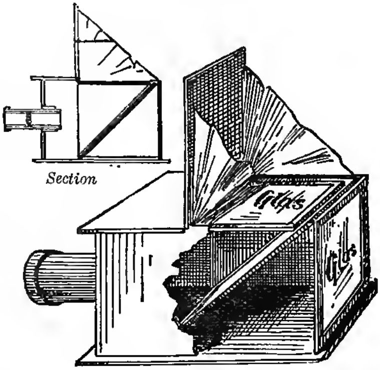
48. Speaking trumpet. This consists of a long, truncated cone, the speaking trumpet proper, and a short mouthpiece attached to it, also conical in shape. Regarded physically, it serves to demonstrate the law of the reflection of sound. To make it, first draw the net of the large cone. Edge, 37 cm.; diameter at the wide opening, 12·5 cm., at the narrow one, 2·5 cm. Remember that in the case of round bodies the lining is done before the rolling. The jacket of the cone drawn and lined, roll it over a suitable shape, using several layers of blotting-paper; close with glue; cut off to measure; edge at top and bottom with calico. Then make in the same way the small cone for the mouthpiece. Edge, 2 cm.; diameter at top, 4 cm. The mouthpiece is thrust into the larger cone and connected with it by means of calico. Lastly, the two united cones are covered. For lining, choose red glazed paper; for covering, dark imitation calf. The technical reason for introducing the speaking trumpet here is its conical shape.

49. The centrifugal railway. (After Weinhold.) A grooved rail having a V-shaped section descends for some distance in a straight incline, while at the bottom it is bent round into the form of a circle (or, more strictly speaking, into that of a spiral screw). A ball of lead or glass placed at the top of the groove, owing to the velocity it acquires in the first part of its descent, travels round the curved part of the groove without falling. The reason is that centrifugal force presses it to the groove more strongly than the force of gravity draws it downwards. (Weinhold, 3rd edition, p. 106.) The base may be either a wooden board or an open box of wood-pulp. Dimensions of box:—46 × 13·5 × 4·5 cm. The upright is likewise either of wood or made of wood-pulp in the form of a blunted hexagonal



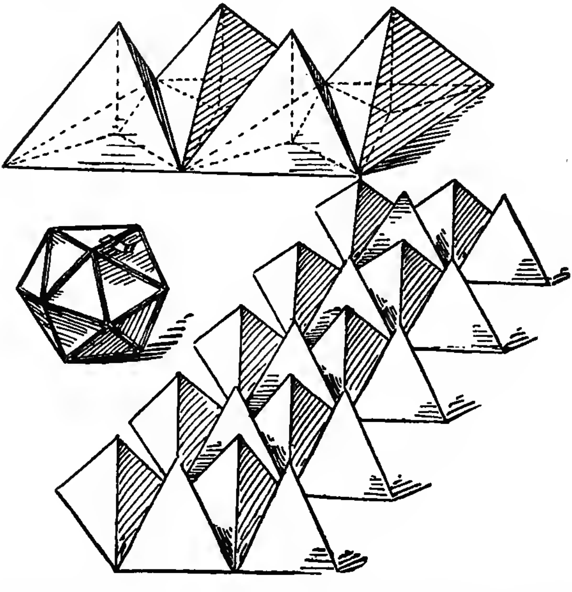
pyramid (length of edge, 30 cm.). The lower, larger hexagon may be of 6·5 cm. side, the upper of 3 cm. The box below and the pyramid are for the sake of stability edged with calico (after the glueing together) and covered with paper stained to imitate wood. The box is lined with unbleached paper of one colour. The making of the groove is more difficult; but the difficulty is not insurmountable by a pupil who has made some progress. To give the method in full here would tax our space too much. The best plan is for the master to do the work before the boy. Those, however, who require exact particulars will find them in Weinhold, pp. 106, 107; English translation, pp. 150, 151.

50. Camera obscura. (See Glass-Work, No. 7.) This object has been introduced into our course as an exercise in the making of a composite box, bottom and lid projecting, and also as an example of the application of the hinge. The camera obscura is, as the name implies, a dark chamber, the front being furnished with a movable tube in which a lens is fixed. The upper side of the camera consists in part of a sheet of ground glass, by which the image is received when reflected from the mirror. The composite box is first made. Dimensions:—20 × 17 × 13·5 cm. Bottom and lid, both bordered, project as shown. The box is lined with black paper, and covered with good paper of one colour. The lid of the box is so constructed that one-third is fixed;



the other two-thirds are movable by means of a hinge. To receive the image, a sheet of ground glass may be fixed at the back of the box; the camera then works like a photographic apparatus. The size of this sheet of glass obviously depends on that of the back of the box. The box made, the holders for the slanting mirror are next glued in. These holders are thus obtained:—Two squares of board of a suitable size are covered with black and cut diagonally. The triangles are glued right and left on the sides of the box so that the hypotenuses are somewhat apart—so far apart as to allow the sloping mirror to pass freely between them. Dimensions of mirror (which is backed with board, edged, and covered at back), 18 × 16 cm. The upper ground glass, which receives the image from the mirror, is likewise edged with calico. One of its dimensions depends on the width of the box, the other may be 12·5 cm. It now remains to make the tube for the lens. Let the lens have a diameter of 4·5 cm. About a roller of the same diameter a cylinder (10·5 cm. long) of blotting-paper is rolled. This cylinder is lined with black paper and covered; at its front or outer edge it receives a raised rim, rolled from blotting-paper and covered. This rim prevents the tube when thrust back from going right into the camera. To keep the lens upright in the tube, we make a narrower cylinder (black lined and covered) fitting into the tube. This cylinder, which is 10 cm. long, we divide in the middle into two rings, one being thrust in front, the other behind the lens. Inside the camera, around the front opening, a cylinder 3 cm. long is fixed; its diameter is such as to allow the tube to move freely in it. The tube has thus a support as it is moved to and fro. Lastly, foot-plates may be glued under the four corners of the box.

51. Icosahedron, resolved into twenty congruent pyramids. A piece of cardboard-work requiring great accuracy. As material, choose grey cardboard, not too thick; and for edging, black calico. Our first object is to erect twenty equal pyramids, their bases being equilateral triangles all of the same size. The apices of the twenty pyramids must ultimately meet at the middle point of the icosahedron. If the edge of the pyramid is too short, the apices will have a space between them; and if it is too long, the icosahedron will not close. The length of the edge of the pyramid, which as being also the radius of the sphere about the icosahedron, we call r, depends on the length of the side of the equilateral triangle which forms the base. Denoting the length of that side by k, we have the following formula to connect the values :—

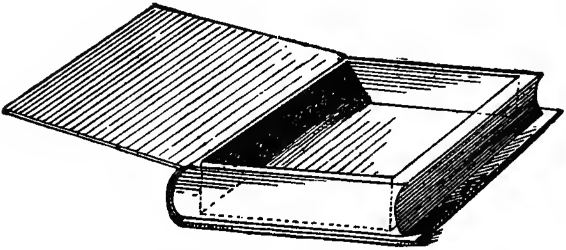


$$r = k\frac{\sqrt{10+2\sqrt{5}}}{4} = 0{\cdot}951k = \frac{19}{20}k.$$

Thus, if we take the side of the equilateral triangle at 9 cm., the edge of the pyramid will be 8·56 cm.

We begin the construction, then, by making to these dimensions twenty pyramids with triangular bases. Each set of four is joined by a strip of calico along edges of the bases in the way shown in the *upper* figure. The five groups of pyramids obtained are then connected as shown in the *lower* figure. The twenty pyramids thus joined will, if the work be true, close into an icosahedron. It remains to border those edges which were not affected by the joining operation. Closing the icosahedron firmly, we glue strips of calico over those edges which are still uncovered. When the glue is dry, we cut through the middle of the strips so that the solid can be opened again. To assist in keeping the whole closed when necessary, in the middle of one edge we attach a tongue of cardboard covered with calico. This tongue is thrust through the adjoining calico border, which must be left unglued at the place in question. The whole model will serve as a proof that the maker has learned to work with precision.

52. Sham book. We give this exercise to have in our course an example of fluting. Material: — fairly thick board and blotting-paper. Inner measurements of box:— 21 × 14 × 4 cm. The covers project at the top and bottom edges of the sides, 4 mm.; in front, 6 mm. The four side-parts are set up on a blotting-paper base (the lower cover). The back and front pieces must be concave (fluted); they also are made of blotting-paper. Small props are fixed to



support the back. The hinge of the upper cover is a strip of linen 4 cm. wide, half of which is glued to the box before covering. The box part is finished first; then the upper cover is made with corners and back as in the case of the portfolio. The unglued half of the linen strip is next smeared with glue and attached to the upper cover. Lastly, a mirror is inserted of the size of the box.

Herewith ends our course of Cardboard-Work. We do not claim that it is complete, but are convinced that the boy who has gone through it will have gained considerable technical skill, and be equal to any difficulties which may arise in other work of the same kind.

B. BENCH-WORK.

Bench-Work, as might be expected from its nature, takes its subjects more especially from domestic utensils, and yields less readily than Cardboard or Metal Work to an attempt to enlist it in the service of school instruction. Nevertheless, the work is so favourable to the physical development of the young, and technically so interesting, that we cannot renounce the endeavour to utilise it in our present course. Nor is it necessary that we should. For, firstly, there is a large number of objects suitable for our purpose which can be made independently—that is, by Bench-Work only; and secondly, Bench-Work serves as an auxiliary to Metal-Work, being used in the making of stands, frames, etc., to support metal apparatus. This auxiliary work is, naturally, for the most part of a simple kind, and belongs accordingly to the first part of our course. But, in order to introduce such important technical operations peculiar to Bench-Work as edge-curving, dovetailing, housing, joining by open mortise and tenon, etc., we have not hesitated to suggest tasks which, though not strictly belonging to school instruction, are yet closely connected with school life. Such are the drawing-board (No. 42), the try-square (No. 39), the

T-square (No. 41), and the book-shelf (No. 32). The operations to which we have referred are essential to the method of Manual Training, and necessary for all who would become acquainted with the technicalities of Wood-Work. Perhaps there will hereafter be found for Bench-Work other subjects, springing more immediately from the teaching of the class-room. The reader is then begged to accept what we now offer as provisional, intended to form a basis for further efforts in the same direction. Suggestions which may tend to promote the object we have in view will be gladly received. Those, however, who investigate the matter will come to the conclusion which we have reached—that it is far easier to draw up perfectly independent courses of manual work as an adjunct to school instruction when the material is cardboard or metal than when it is wood; and that whilst Bench-Work, as a branch of Manual Training pure and simple, can stand quite alone, it needs assistance when employed for illustration. We give, nevertheless, the exercises which follow in the conviction that they will serve for valuable practice in the use of tools, and convey a knowledge of the *Technik* of Wood-Work, so far as lies within the scope of Manual Training.

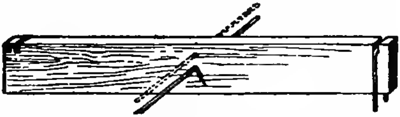
1. **Preliminary exercises** in planing a surface and in cutting with the saw (sawing along the grain and across it).

2. **Base-boards**—to support appliances of various kinds, such as the pivot for the magnetic needle, the electric bell, the rotation apparatus, etc. The sizes are not strictly determined. Exercises in square shooting and chamfering. Use of wood-stain (water or oil), waxing, and polishing.

3. **Plant-label (for school garden).** Material:—soft wood, white deal or Scotch fir. A piece is taken about as broad as the cutting-iron and of convenient length for planing. Two surfaces are dressed parallel to each other, and the edges planed at right angles. The point is then cut, and the top rounded.

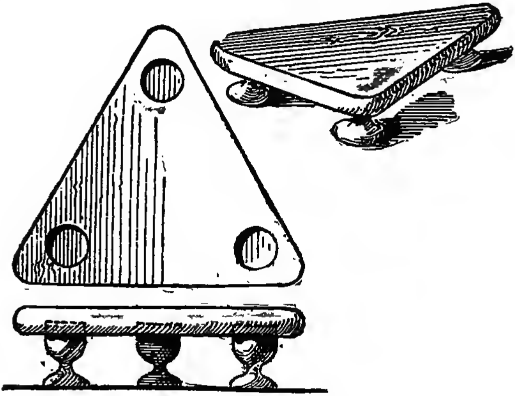
4. **Upright for equilibrium apparatus.** (See Cardboard-Work, No. 35.) Material:—alder. Dimensions:—35 cm. long; diameter, 2 cm. Distance between the holes, 2·5 cm. The upright is first planed square. Then with the marking-gauge we draw on one of the faces the lines between which the series of holes is to be contained, and with the compasses prick points equidistant from one another. At these points the holes are bored. The square upright is rendered octagonal by paring off the edges. The eight edges are evenly pared so that we get sixteen, the sixteen so that we get thirty-two. The upright is then made cylindrical by the use of sandpaper. Lastly, the top is rounded with rasp and file, and the whole stained.

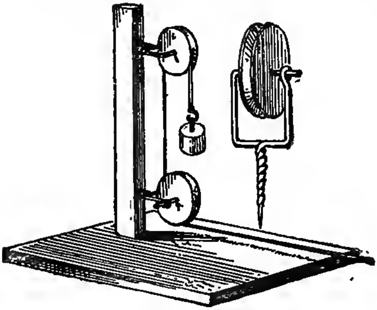
5. **Simple apparatus for illustrating the laws of the common balance.** Material:—maple. A piece of wood is taken, say, 26 × 3·4 cm. × 6 mm., and carefully planed. At right angles to the length, and where the centre of gravity is, is bored a hole, as also another hole above the former, but close to the upper edge of the beam. Through these holes knitting-needles are passed. On the upper surface of the beam, a few millimetres from either end, we saw notches in which thin U-shaped wires can be hung. The beam is then finished, and serves to show the dependence of the turning of the balance upon the position of the point of suspension. The planing of the wood is simple work, but, by reason of the experiment to be performed, requires to be carefully done.



6. **Insulating stool.** (See Glass-Work, No. 11.) Material:—Scotch fir. The top has the shape of an equilateral triangle of 45 cm. side, and is from 2·5 to 3 cm. thick. Probably it will not be easy to obtain a board of the necessary size; thus the student must learn to apply his skill in joining two boards together with glue. This done, the

joined boards are planed to thickness, the sides of the triangle are set out, and the position of the holes for the glass legs marked. The holes are bored or chiselled to one-third or one-half the thickness, and the triangle is then cut out. The edges of the sides of the triangle are rounded with plane and file, the top is stained, and the three glass legs (short, strong grog-glasses will serve) secured in their places. This last operation is performed by heating the glasses until they will melt sealing-wax, placing a layer of sealing-wax in the holes, and pressing the glasses firmly in.

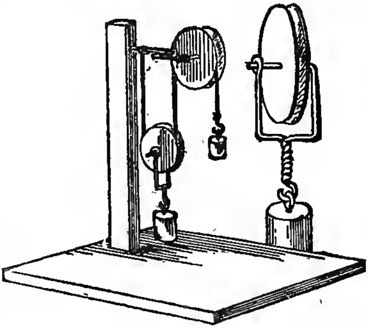




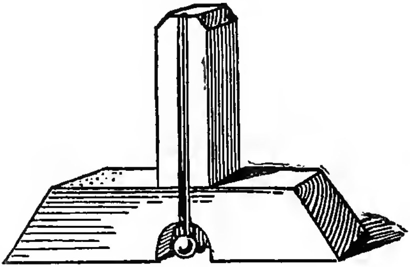
FIXED PULLEY.

7. Support for fixed or movable pulley. (See Metal-Work, No. 39.) Material: — Scotch fir. Dimensions: — base, 25 × 15 cm. × 20 mm.; upright, 32 cm. long; cross-section, 22 mm. square. The base-board and upright are planed, then mortise and tenon are set out with the marking-gauge, the tenon is cut at the bottom of the upright and the mortise chiselled in the base. When we have chamfered the edges of the base, glued the upright in, and stained the whole with walnut stain, the woodwork is finished.

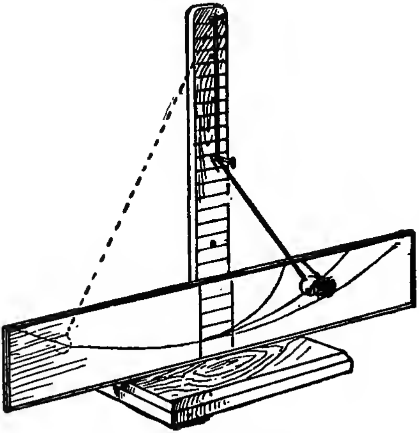
The shaping of the wires for the pulleys belongs to Metal-Work. As for the pulleys themselves, we may cut out discs with the saw and use the round file to groove the edges, or we may procure them from the turners. It is simplest to employ the same upright for both the fixed and the movable pulley, attaching one on either side.


MOVABLE PULLEY.

8. The level. Material:—Scotch fir. Dimensions:—vertical block, 30 × 7 × 2 cm.; horizontal block, 30 × 7 × 4 cm. When the two blocks have been dressed, we set out the tenon on the vertical one and cut it; the mortise in the lower we likewise set out and cut with the chisel. Then the two parts are glued together. The upper block is chamfered at the top, the ends of the lower one bevelled. Lastly, the hole for the bob is bored out, and the pendulum fastened in the middle line.



9. Apparatus to illustrate the law of mechanical work. (Paper strips, Cardboard-Work, No. 9.) The apparatus in its simplest form will serve, in the first instance, to elucidate the laws of the pendulum. For this purpose we bore a hole through the middle of the upright near the top, pass a small brass wire into it, and draw through a piece of string at either end of which a leaden bullet is attached.



We are then enabled to lengthen or shorten the pendulum at will, using as our guide a scale marked on the side of the upright. We can thus perform the common experiments with the pendulum. But the apparatus may also be made to show Weinhold's experiments illustrative of the law of mechanical work. If the pendulum hangs free throughout its length, it describes the wide arc; if in the middle of the upright we insert a nail, and cause the string to hang on the left—from the spectator—side of this nail, the bob describes a shorter arc; if the nail be placed lower down, the bob describes a still shorter arc. These shorter arcs are on the right; the arc on the left remains unchanged. Thus our experiments exhibit the truth of the law: — The velocity attained by a body acting under the influence of the force of gravity is independent of the form of the path it traverses, and depends solely on the vertical height of the space through which it passes. (See

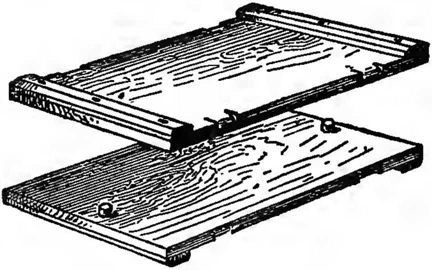
Weinhold, *Vorsch. d. Experimentalphysik*, 3rd edition, p. 57; Eng. translation, p. 76.)

The technical instruction is simple. All that is required is practice in joining by mortise and tenon. Alder wood will be found most suitable. Dimensions:—base, 13×19 ×1·5 cm.; upright, 40×4×1·5 cm. The tenon cutting and mortise chiselling are done as in No. 8. Then the chamfers on the base are set out and cut; the divisions are marked on the upright, and it is rounded at the top; in its middle line the requisite holes are bored; it is glued into the base, and the whole of the woodwork is stained.

10a. Centre of gravity of a scalene triangle. To have as homogeneous a body as possible, we choose maple wood. The exact shape of the scalene triangle is immaterial; it is necessary, however, that the board should be carefully planed to the same thickness throughout. Taking a maple board, say, 8 mm. thick, and planing the two faces, we set out the triangle. The sides of this triangle are bisected, and the points of bisection joined to the angular points opposite to them. The centre of gravity of the triangle lies in each of the lines so drawn, and is thus at their intersection. The triangle is now cut out, and its edges planed true. Rings by means of which the figure can be suspended are screwed in the middle of each narrow edge, in the direction of the lines in which the centre of gravity is. A similar ring by which the triangle can be suspended is screwed in at the centre of gravity in a direction exactly vertical. The whole of the work requires great care in execution.

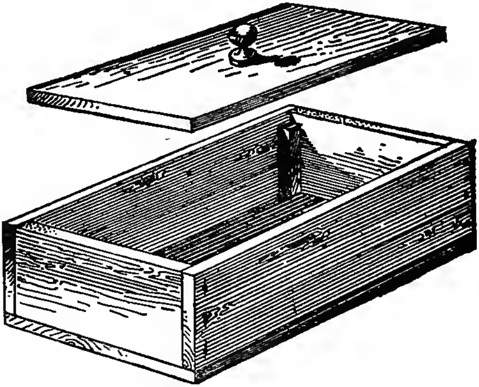
10b. Centre of gravity of a pentagon. Material:—maple wood, 8 mm. thick. The sides of the pentagon may be of any length the worker pleases; but here again care must be taken to plane the board to the same thickness throughout. This done, the pentagon set out and cut, the edges planed true, small brads by which the figure may be hung up are driven into the narrow edges at the five corners. We then, suspending the pentagon by these brads, ascertain the lines in which the centre of gravity lies (a plumb-line hung in front enables us to mark the directions), and these lines are drawn with the marking-point. The intersection of the lines is the centre of gravity, the point at which the pentagon must be suspended or supported to be a equilibrium.

11. Plant-press. Material:—red deal. Dimensions:—20 × 32 × 1 cm. The task here is to make two boards of exactly the same size. To prevent warpage, four strips are planed, as long as the press is broad, and screwed, two to the upper side of one board, two to the lower of the other, as shown in the drawing. In order that the straps which exercise the pressure may keep in position, and not be injured by the sharp edges, these edges are neatly rounded with rasp and file at the places where the straps are to come. Lastly, that the boards may not slip when the straps are drawn tight, small dowels or round pins are let into the middle of the lower board near its ends, holes to correspond to these dowels being made in the upper board. As the whole press is light, by passing a band through the straps it may be carried on the shoulder and taken by the boy on his botanising excursions. The advantage gained is that the plants may be pressed whilst they are still fresh.

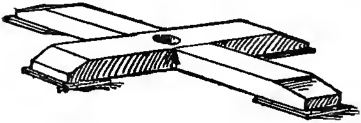


In doing the work it will be best to observe the following order:—cut the boards, plane them, bevel edges, bore holes and screw on the strips, bore holes for dowels, make and insert dowels, trim the edges evenly, round the places for the straps.

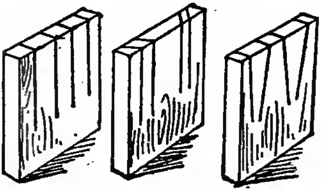
12. Nailed box with lid fitting in. Dimensions :—wood, 12 mm. thick; long sides, 18 cm.; ends, 11 cm.; height, 6 cm. Material :—alder. The four boards for the sides and ends are planed in one piece, which is then cut with the saw; similarly with bottom and lid. The four corner-pieces on which the lid is to rest are glued accurately in their respective positions *before* the box is put together. The reason is that their presence facilitates the nailing of the sides to the ends. These pieces must be lower than the inside of the box by 12 mm.—that is, by the thickness of the lid. When the sides and ends of the box have been joined and the heads of the nails sunk, the upper and lower edges are carefully smoothed with the trying-plane. Then the bottom, which has been left of ample size, is fastened on with thin glue; it is after this that its edges are planed. (Note : plane the ends across the fibres first.) The sides and bottom are finished; the lid is made to fit in, and a handle is glued into it.



13. Cross-shaped foot for pivot-stand. Two strips of Scotch fir are dressed in one piece, afterwards cut. Dimensions :—20 × 3·5 × 1·5 cm. The joint is that known as the lap-halving joint. We lay the two pieces across each other, and draw with the marking-point the lines where they cross; then with saw and chisel cut out half the thickness of each. The next step is to chamfer the ends, lay the pieces one on another, and bore the hole through both. Lastly, prepare four square supports, and glue them on.



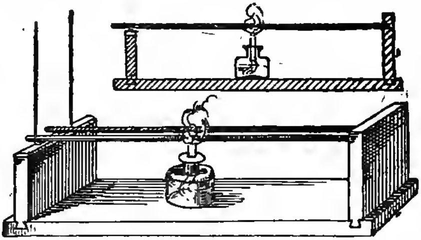
14. Sawing—three kinds of. Take a piece of alder wood (15 × 10 × 2·2 cm.) dressed and planed; divide it into three parts; plane the ends and practise the saw-cuts—that is, saw straight with the grain, obliquely with the grain, and across the grain. Faultless execution proves mastery of the saw.



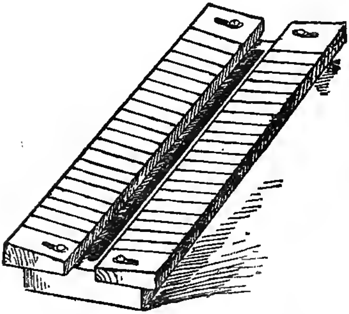
15. Corner joined by groove and tongue. The two corner-pieces are made from one board of Scotch fir and planed—the dimensions being immaterial. On one part a groove is cut across the direction of the fibres with the groove-saw. [This is not a tool used by English carpenters, but has been introduced for Slöjd.] On the other piece a tongue is made to fit into this groove. Groove and tongue must be so placed that the outside of one board is flush with the end of the other. It will be necessary for the teacher to give oral instruction in the method of proceeding. The joining of the corner in this way is an introductory exercise to No. 16.

16. Box—corners joined by groove and tongue, lid rebated. Dimensions:—thickness of wood, 1 cm.; box, 23 × 13·5 × 8 cm. Material:—Scotch fir. The board for the sides and ends is planed in one piece, then divided; and so with bottom and lid. The sides and ends are then joined by groove and tongue, and glued together. The upper and lower edges of the frame so formed are accurately planed with the trying-plane so that bottom and lid may be applied. The bottom is glued under, the rebate on the lid planed with the rabbet (*i.e.* rebate) plane, the lid fitted into the box, and the whole finished with sandpaper.

17. Apparatus to exhibit the unequal expansion of metals by heat. (See Metal-Work, Nos. 20 and 28; Glass-Work, No. 1.) Dimensions:—base, 38 × 9 × 1·5 cm.; right side-piece, 9 × 8·5 × 1·5 cm.; left side-piece, 9 × 7 × 1·5 cm. Material:—alder wood. The two vertical side-pieces are joined to the base by dovetail-housing. In the right side-piece, the higher of the two, holes are bored through half the thickness of the wood. These are to receive bars of different metals—let us say, iron and brass, *i.e.* copper-zinc. The bars are inserted in the holes so that they press on the inside, and cannot expand in that direction. Their other ends rest on the left or lower side-piece. If we jam under each of the free ends a piece of thin brass wire bent at right angles, the long upright arm of the wire angle serves as an index to the amount of expansion. Thus, if we heat the metal bars in the middle, they expand and cause the short arm of the wire angle beneath them to turn. The smallest movement of the short arm is communicated to the long one and clearly indicated. The metals, being unlike, expand, when heated equally, in unequal degrees, and the index fingers are turned through unequal angles.

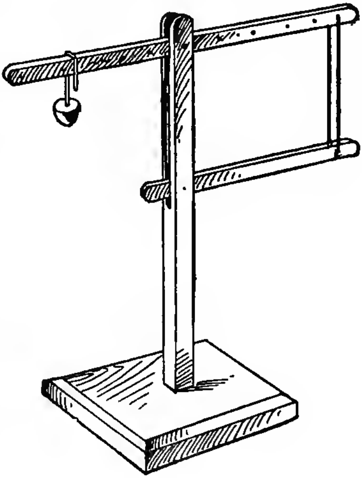


18. Straight edge. Dimensions:—1 m. × 6 cm. × 8 mm. Material:—alder. The task here is to plane accurately a lath or strip of wood, long in proportion to its breadth and thickness. First plane up the faces; then plane the edges straight so that the breadth is the same throughout; lastly, square the ends (square shooting).



19. Board for mounting butterflies. Material:—alder. Dimensions:—length of side-rests, 36 cm.; breadtb (together), 12 cm. The cross-section of the side-rests is wedge-shaped, the thickness at the outer side being 14 mm., at the inner 11 mm.; strips for the framework underneath, 22 mm. square in cross-section; length of the framework, 34 cm.; of the cross-pieces, 12 cm. The strips for the framework are planed and joined by lap-halving. Then comes the planing of the groove for the layer of cork, and the glueing together of the framework. The side-rests are next planed, the elongated holes for the screws (enabling the rests to be moved) bored and chiselled, and the lines across the rests drawn with the marking-point. Lastly, the under framework is neatly finished, the layer of cork glued in, and the side-rests attached with screws.

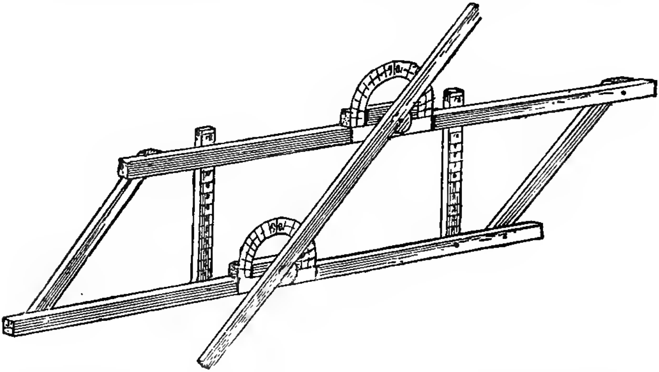
20. Lever—single or double armed. Material:—alder. Dimensions:—base-board, 13 × 13 × 1·5 cm.; upright, 35 cm. and 2 cm. square in cross-section. Double-armed lever, 40 cm.; single-armed, 23 cm. long; both 2 cm. broad and 7 mm. thick. The upright is fixed in the base by mortise and tenon, as in previous exercises. The lever arms and the upright are rounded at the ends by one operation. Then the slit in the upright is cut and the wood chiselled out; the holes in the arms and in the upright are bored. Lastly, the upright is glued into the base, and the apparatus finished with sandpaper. The making of the weights belongs to Metal-Work.



21. Arrangement for illustrating the parallelogram of forces. (See Metal-Work, No. 34.) Material: — alder. Dimensions: — base, 37 × 20 × 2 cm.; uprights, 38 × 2 × 2 cm. The technical construction of the woodwork will be found simple enough after the exercises which have preceded. When the parts have been cut and planed to the given dimensions, tenons are made, in a way that will be by this time familiar, on the uprights, and mortises to receive them chiselled in the base. The edges of the base and the tops of the uprights are rounded. The making of the movable supports for the pulleys, and of the weights representing the component forces and the resultant, belongs to Metal-Work, and is discussed under that heading.

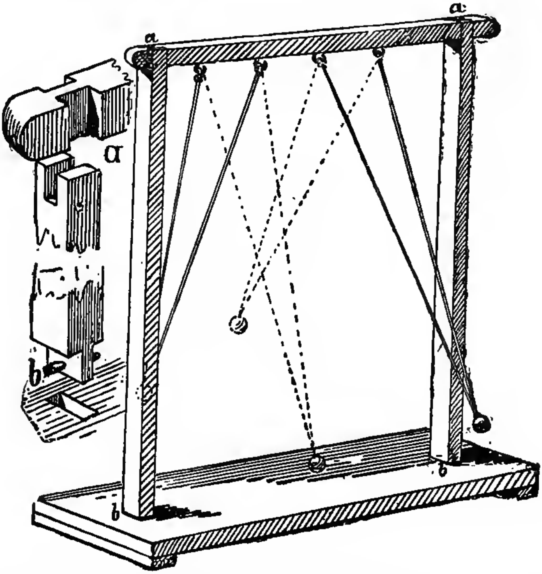
22. Framework for Differentialrolle. (See Cardboard-Work, No. 20; Metal-Work, No 24.) Material:—alder. Dimensions: — base, 32 × 20 × 1·5 cm.; uprights, 53 × 2 × 2·2 cm.; cross-piece at top, 28 × 2 × 2·2 cm. Tenons are cut on the uprights, and inserted into mortises in the base as before. New is the joining of the cross-piece to the uprights by open mortise and tenon, the process being also known as slotting. Keeping the marking-gauge set in the same position, we set out the tenons on the cross-piece, and the slots or open mortises on the two uprights, then cut both tenons and mortises. The parts of the framework are glued together, and the whole finished with sandpaper. Lastly, the edges of the base are chamfered, and the woodwork is stained and waxed.

23. Arrangement of wooden strips to illustrate Euclid I. 29. (After Kumpa, Model 22.) Technically the work is an exercise in the making of laths or wooden strips. The wood employed is alder. All the strips are planed 1 cm. broad and 7 mm. thick; the two parallels are 60 cm., the four cross-pieces 14 cm., and the strip representing the straight line which cuts the two parallels is 36 cm. long. When the strips have been made, the two parallels are connected with the outer cross-pieces by means of wood-screws; on the *other* side, the side opposite to the cross-pieces, is screwed the cutting line exactly in the middle. (In our drawing the cutting line is on the parallels, the cross-pieces under them. The cutting line can thus be turned without hindrance about the points of intersection.) To measure the varying distances of the parallels from one another, we screw two pieces of wood only to the lower parallel and at right angles to it. These upright strips are



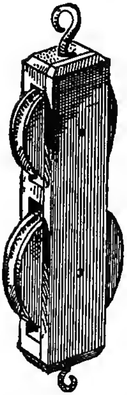
between the two outer cross-pieces and on the same side of the parallels as they—thus in the drawing they are underneath. Before the uprights are screwed on, intervals of 1 cm. are marked on them with the marking-point and also numbered. If the uprights be first varnished, the figures may be *written* on them.

24. Frame for pendulum experiments, for suspending movable pulleys and for other purposes. Material:—



alder. The frame consists of a base-board, say, 68 × 14 × 1·5 cm., two vertical supports 50 cm. high and 1·8 cm. square in cross-section, and an upper cross-bar—from which pulleys, etc., may be hung—3·5 cm. broad and 1 cm. thick. Under the base we may fix either small square blocks at the four corners or strips running across the ends, as in the drawing. Besides cutting with the saw and planing to make the various parts, we have here, in joining them, practice in the cutting of tenons, the making of mortises with the chisel, and the cutting of open mortises. To lodge the cross-bar securely, open mortises are made at the top of the vertical supports, and the wood is cut away at the proper place on the cross-bar to the depth of the open mortise. This is shown in the small drawing to the left, marked *a*. The other small drawing, *b*, exhibits the method of securing the vertical supports to the base: the mortise is made right through the base; the length of the tenon is greater than the depth of the mortise; through the projecting part of the tenon a hole is bored and a strong round peg cut to fit this hole. To complete, chamfer base and round the ends of the cross-bar. It is not necessary to glue the parts of the framework together; they are left free, so that it may be set up and taken to pieces at will.

25. Round lid for Chromic[1] acid element. (See Metal-Work, No. 44; Glass-Work, No 16.) Material:—beech wood. The dimensions of the cover depend on the size of the glass vessel available. The diameters of the two discs may be, say, 8 cm. and 6·3 cm. The two discs are cut round and joined by means of brass nails. The cover thus made is stained and varnished.



26. System of pulleys. Material:—supporting beam, Scotch fir; blocks, alder. We may use blocks with either two or three pulleys. The block for two pulleys is made of an under piece (dimensions:—30 cm. long; 2 cm. thick; breadth, 5 cm. at bottom, 4 cm. at top) and an upper piece of the same dimensions, except that it is only 8 mm. thick. One pulley has a diameter of 10 cm., the other of 8 cm. In making the under piece of the block, we first set out the places for the pulleys, then cut with the saw vertically to the depth marked, and remove the wood between the saw-cuts with the chisel. The inner surfaces are planed with the old woman's tooth-plane. The depth of the incisions should be about 10–11 mm. We next glue the upper piece on, trim it flush with the lower piece, and chamfer the edges at the top and bottom of the block. The pulleys are each made of three discs of equal thickness, say 3 mm., the middle disc having in each case a diameter 2 cm. shorter than the two outer ones. In glueing the three discs together, see that the grain of the inner one is across the grain of the two others; if this is so, there will be no warpage. When the discs have been glued together, we bore through them and through the block the holes for the axles; the pulleys are then placed in position. The axles should not go right through the under piece, but have a good hold in the wood itself; the outer ends are filed to the level of the surface of the upper piece. Lastly, we screw in hooks at the top and bottom of the block to enable us to suspend it.

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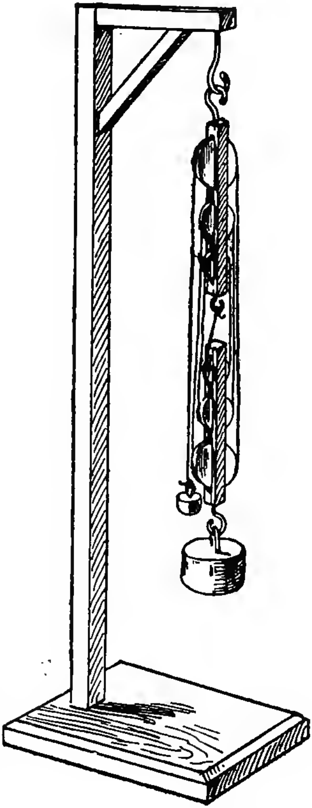
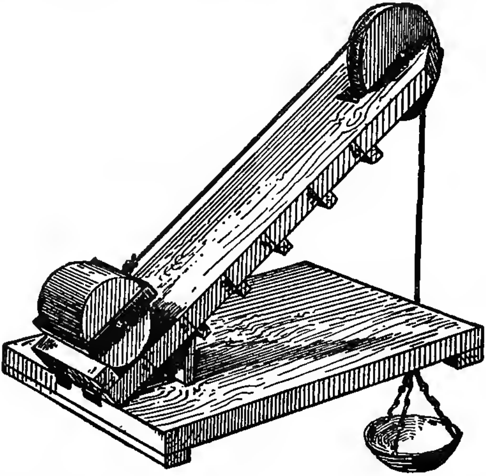
[1] See Hopkins, *Experimental Science*, p. 412.



To construct a block with three pulleys, we proceed in much the same way. The dimensions of the block are here 3·5 × 2·8 cm, the under piece being 2 cm. thick, the upper piece or cover 0·8 cm. The under piece is cut away to the depth of 10–11 mm., 2·5 cm. being left uncut at either end. The end cuts are made with the saw; the wood between them removed with saw and chisel. To smooth the inner surface, we may in this instance use the file. The diameters of the three pulleys are 9·5, 7·5, and 5·5 cm. As before, a pulley consists of three discs, each 3 mm. thick, the diameter of the inner disc being 2 cm. less than that of the outer ones. The rest of the process is the same as in the case of the block with two pulleys.

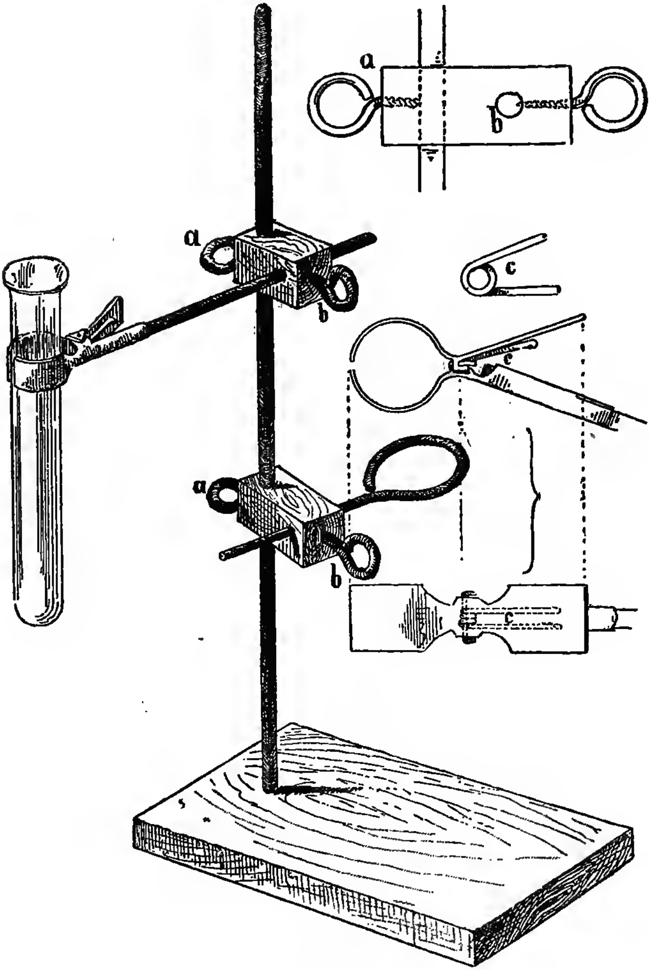
The supporting beam is fixed in a base-board, 25 × 19 × 2 cm.; the dimensions of the upright are 105 × 3 × 2 cm.; of the cross-bar, 19 × 3 × 2 cm.; of the oblique stay, 13 × 2 × 1·5 cm. The upright is let into the base at the middle of its cross-grain end by means of a dovetail, or joined by mortise and tenon. Upright and cross-bar are also connected by means of a dovetail. The making of the oblique stay is an exercise in mitre-shooting; it is fastened in its place with wire nails. Last of all, a large hook is screwed into the cross-bar to enable us to suspend the blocks.

27. Inclined plane. (See Metal-Work, No 35.) Material:—alder. Base-board, 40 × 14 × 1·5 cm.; board for inclined plane, 56 × 5·5 × 1·5 cm.; prop, 6 × 5·5 × 1 cm.; diameter of the pulley, 8 cm. When the boards have been planed, under that which is to represent the inclined plane, at intervals of, say, 43 mm., we glue small strips of wood, 5·5 × ·5 × ·5 cm. At the front end of it, a slit 11 mm. wide and of suitable depth is made for the pulley. The corners near this slit are either chamfered or rounded. The hole for the axle of the pulley (10 mm. thick, and made of three discs as before) is next bored, and the pulley fixed in position. As a stay for the cylinder representing the weight, a cross-piece is glued and nailed at the bottom of the inclined plane. The latter is connected with the base-board by means of a hinge screwed on the outside of the two boards joined. The prop is of beech; its upper edge, upon which

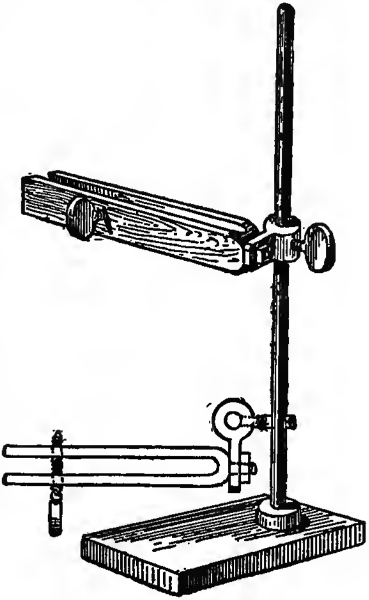


the inclined plane is to rest, is planed to an angle of 45° (mitre-shooting).

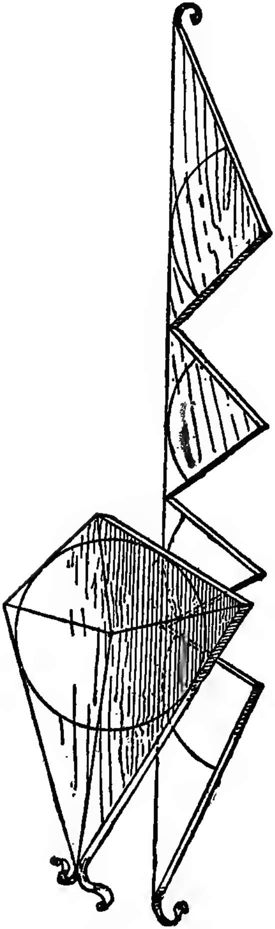
28. Retort-stand and tube-holder. (See Metal-Work, No. 29.) Material:—beech. Base-board, 22 × 12·5 × 2 cm. Upright rod, 46 × 1·8 cm. (The diameter of the rod will probably be determined by the size of the centre-bit available.) Wood-blocks, 8 × 3·5 × 3·5 cm. The movable blocks are secured to the rod by wood-screws (see figure *a*). A second hole bored horizontally through the block, receives the actual tube or retort-holder. On one tube-holder is a holdfast or gripper made of tin-plate. The construction of this holdfast is easily seen from the special drawing given. The special spring *c* presses the jaws of the holdfast together. The lower block receives a stout brass wire bent as shown, and serving to support a small evaporation pan or saucer. The tube-holder and saucer-holder are both secured in the blocks by means of screws (see *b*).



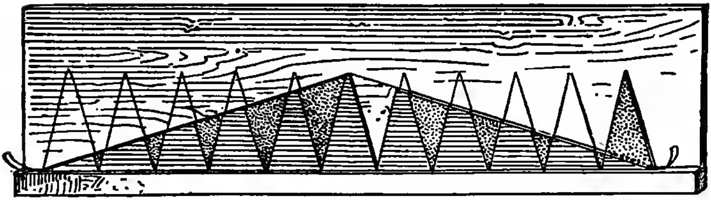
Instead of the metal holdfast, we may make a wooden fork to hold test-tubes, etc. Such a fork is represented in the drawing annexed. The wood chosen for the fork is beech. Dimensions:—25 × 3·5 × 3·5 cm. When the wood has been planed to size, we cut a tenon at one end and round it into cylindrical form. The wood between the two arms of the fork is removed. A screw inserted towards the open end of the fork enables us to bring the two arms towards each other and so hold the tubes firmly. This screw works loosely in the front arm, whilst biting strongly in the back one. To prevent the tubes from slipping and to reduce the danger of breaking them, we may glue a layer of cork to the inside of the fork. To fasten the fork to the upright rod, we fix the tenon cut and rounded to a small block, as shown in the drawing.

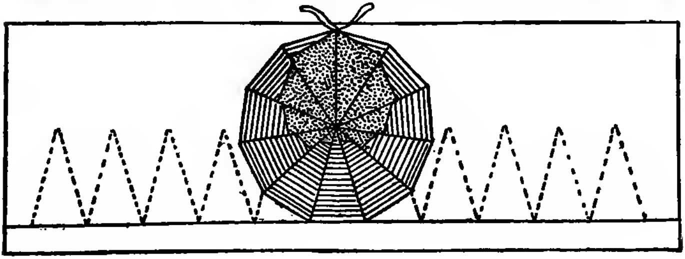


29. Quadrilateral described about a circle. This exercise serves as practice in the accurate cutting of wood into parts, and is an illustration of the proposition that when a quadrilateral is described so that its sides touch a circle, two of its sides are equal to the other two sides. The best wood to use is beech, 1·5 cm. thick. Taking a board, we plane it to thickness, and then set out the drawing on the upper surface. The simplest way of doing so is to begin with a circle of any diameter that the worker pleases—say, 14 cm. In the circle we draw four radii, the angles at which they are inclined to one another being indifferent. Through the points in which the radii cut the circle draw perpendiculars—that is, tangents to the circle, and produce these tangents until they meet. The angular points of the quadrilateral thus formed are joined to the centre of the circle by straight lines. Along these lines we cut carefully with a saw set as fine as possible. The next step is to cut along the lines which bound the quadrilateral. The edges are planed smooth and the four parts glued, as shown in the upper figure, to a strip of linen, care being taken that each part is in actual contact with the adjacent one. The strip enables us to close the quadrilateral or resolve it into its parts at will. The lower figure represents it closed. Last of all, the wood is stained, the circumference of the inscribed circle traced afresh and marked with opaque white, in order that it may stand out well from the dark background.

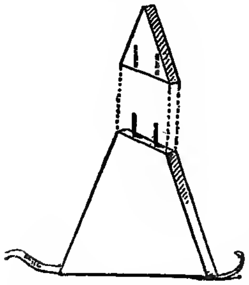


30. To illustrate the method of calculating the area of a polygon. (See Kumpa, Model 70). The area of a regular polygon is equal to the area of a triangle having as its base the perimeter of the polygon, and as its altitude the perpendicular from the centre of the circumscribed circle to one of the sides of the polygon. The figure shows the resolution of a regular hendecagon into eleven triangles, which are combined, as it were, into one large triangle having as a base the sum of the bases of the eleven triangles and the same altitude as each of them. The lower figure exhibits the eleven triangles united to form the hendecagon.



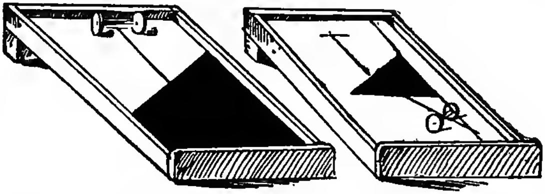


The following is the method of construction. The dimensions of the back-board, which is of red deal, are 70 × 28 × 1 cm. Two cleats to run across the grain on the right and the left are 28 × 2·5 × 1 cm. The strip along the foot is 73·5 × 1 × 1 cm. The regular hendecagon must be described in a circle about 23 cm. in diameter, and the eleven triangles obtained by drawing lines from the centre of the circle to the angular points of the hendecagon. These triangles are now cut from an alder board, 5 mm. thick. To avoid waste of wood, the triangles are cut in pairs, each pair forming a quadrilateral. Their edges are then planed so that the triangles correspond exactly with those in the drawing, and are all equal to one another. The back-board having been made of the required thickness, tongues are planed on its right and left sides with the plough. The cleats are then prepared and provided with grooves into which the tongues fit. These cleats are glued to the back-board, the object being to prevent warping. The strip along the foot is attached by means of glue, and further secured with wire nails. The eleven triangles are next glued by their bases on to a narrow linen tape, so that each is in contact with the adjacent one. The row of triangles is laid tentatively along the foot-strip in such a way that the vertex of the midmost triangle lies on the middle line of the back-board. (An odd number of triangles must thus be taken, in order that there may be a midmost.) We mark carefully the position of the vertex of this midmost triangle, and also the two end points of the base-line of the row of triangles. Removing the row from the back-board, we draw with the marking-point sharp lines to join the point where the vertex lay to the points at the ends of the base-line. We in this way obtain the outline of the large triangle which represents the sum of the areas of the eleven small triangles. The row of triangles is next replaced on the back-board in the same position as before, and the *midmost* triangle secured to it with screws. The five triangles at either side are left free. Last of all, lines are drawn with the marking-point from the vertex of the midmost triangle to the ends of the base-line of the row, this time across the faces of the small triangles. That the large triangle is equal to the eleven small ones may be shown in either of two ways: (1) we may stain or paint the



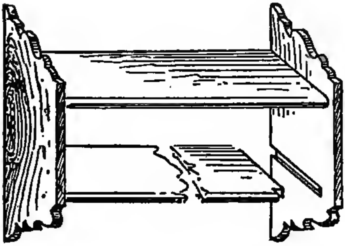
small triangles and the intervening spaces up to the line across them, and point out that the uncoloured parts of the triangles fit, in reverse order, into the intervening space below the line; or (2) we may actually cut through the smaller triangles and fit the upper parts into the intervening spaces. The latter method is easy enough. In each triangle two wire nails are driven into the lower part, perpendicular to the base, not to the intersecting line; these are received in holes made in the upper part, as shown in the small drawing.

31a and 31b. Illustration of the refraction of a ray of light upon entering a new medium. (See Metal-Work, No. 33; Glass-Work, No. 2.) This apparatus was devised by Herr R. Schmidt of Leipzig to exhibit the refraction of light. A metal roller runs down a sloping base consisting partly of glass, partly of coarse plush. As the roller has but little friction to overcome on the glass, but much on the plush, the side which in the descent comes first to the border-line between plush and glass is retarded, whilst the other side continues to travel on the glass with the same velocity as before. The consequence is that the roller turns and is visibly diverted in its course. This is shown by the apparatus represented in the left-hand drawing. The right-hand sketch gives us an illustration of the direction of a ray of light entering and leaving a prism.

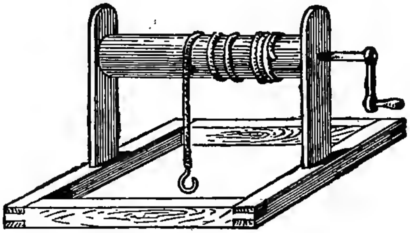


As far as the woodwork is concerned, the two appliances may be made in the same way and to the same dimensions. For the base-board we take Scotch fir; for the other parts, alder. Base-board, 41 × 25 × 1·5 cm.; the sides and ends depend as to length on the base-board; height, 1·5 cm.; thickness, 1 cm. The base-board made, to give it the necessary inclination we fasten under its upper end a strip, 3 cm. high, 1·5 cm. thick, and as long as the board is broad. The fastening is by driving in nails from above. The edge of this strip which rests on the table is planed obliquely to the requisite angle. The sides and ends planed, a groove is made in them to receive the glass; the ends are mitred at the proper length. The plush is now laid on the board, as also the glass. Under the latter is white drawing-paper, on which are traced the line of incidence and the line of refraction. The framework (sides and ends) is joined together and nailed to the base-board. Lastly, to prevent the roller from falling off, a strip (25 × 3·5 × 1 cm.) is nailed across the bottom, its upper edges and corners being rounded.

32. Book-shelf. Dimensions:—thickness of the wood, 15 mm.; side-pieces, 55 cm. high, 17 cm. broad; cross-boards, 49 cm. long, 16 cm. broad. Material:—alder wood. When the four boards have been made to size, the cross-boards are united with the sides by a housing joint. Grooves are made in the sides, and the cross-boards are planed to fit exactly into these grooves. The sides are curved at the top and the bottom, the front edges of the cross-boards rounded, and the whole fitted together.

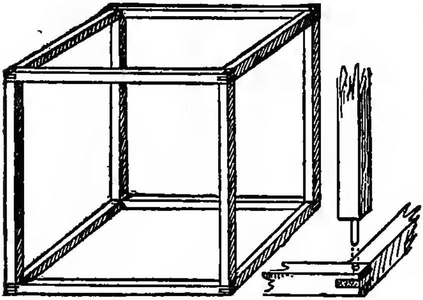


33. Windlass. The framework resting on the ground is made of alder, all the rest of beech. This framework consists of four pieces (25 × 4 × 2·5 cm.) joined together by open mortise and tenon, and is made first. Then the upright supports (21 × 5 × 0·7 cm.) are prepared. At their lower ends tenons are cut; the upper ends are rounded, and through them the holes (1·5 cm. in diameter) to receive the axle of the roller are bored. The next step is to make the roller; it is 26 cm. long, and has a diameter of 3·5 cm. Before the roller is rounded—in the way already practised—the two axles are cut (1·5 cm. and 5·5 long) and made round; but at the end of the longer a square block is fashioned with saw and file. This block is for the handle to fit on to. The roller may now be rounded. On the side-pieces of the ground framework the mortises to receive the tenons of the upright supports are set out and chiselled, the length of the roller being the guide to their exact position. The various parts may then be fitted together and glued. The handle consists of two pieces at right angles to each other. At the upper end of the vertical piece, a square hole, into which the square block on the axle fits, is cut with the mortise chisel. At the other end there is a round hole made to receive the horizontal part of the handle. These two holes are cut before the outline of the vertical piece is sawed. Lastly, the horizontal part of the handle is prepared, the end being made to fit into the round hole in the vertical piece. A brad driven through at the inside of the vertical piece will prevent the horizontal part from working loose.

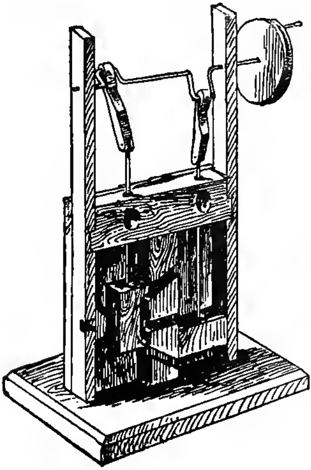


34. The cubic metre. This is made of eight pieces, 1 m. long, and with a cross-section 2·5 cm. square, and four pieces, 95 cm. long, and having also a cross-section 2·5 cm. square. From the eight pieces first mentioned two frames are constructed, being joined by open mortise and tenon.

These frames represent square metres, and form the top and bottom of the cubic metre. The four pieces are for the vertical supports between the square frames. In their ends iron pins are inserted, and to receive these pins, holes of the same size are bored through the joints of the frames. This done, the whole may be fitted together.



35. Model to illustrate the cylinder of a steam-engine. (See Metal-Work, No. 49.) Material:—beech. Base, 19 × 13 × 1·5 cm. Two uprights, 35 × 2·5 × 1 cm. Cross-beam at top of cylinders, 13 × 4 × 2·5 cm. Vertical piece between cylinders, 14 × 3 × 2·5 cm. Block in left-hand cylinder to illustrate action of spanner,[1] 5·5 × 2·5 × 2·5 cm. Wood for piston, 7·5 × 2·5 × 2·5 cm. Back-piece, 19 × 14·5 × 1 cm. Pulley, 1 cm. thick, 6 cm. in diameter. The uprights are fastened into the base by mortise and tenon, each upright having only one tenon and that on its outer side. The cross-beam is set out according



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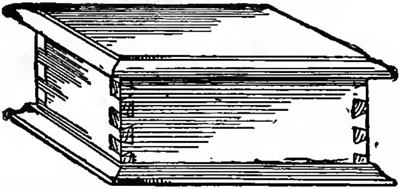
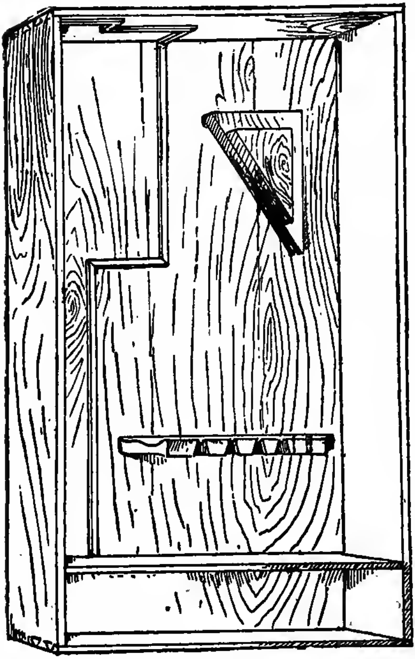
[1] See Hogg's *Elements of Natural Philosophy*, p. 211.

to the distance between the uprights, and fitted into them by means of a groove. To facilitate the movement of the wires on which the piston and the block are fastened, holes are bored in the cross-beam, as shown in the drawing. We next fix in position the vertical piece between the cylinders by means of housing joints. The grooves to represent induction and exhaustion valves are cut across the vertical piece. The various parts are now secured together with glue, and the back-piece screwed on. The piston and the block in the smaller cylinder are placed in position when the metal-work on which they depend has been done. For the sake of clearness, we may paint the valves red, piston and block iron-grey; the base and the rest of the woodwork should be stained brown.

36. Corner joint by dovetailing. A fairly long piece of Scotch fir, the exact dimensions are indifferent, is planed on both sides and made exactly rectangular (square-shooting). The board is divided into two parts, and on the cross-grain edge of one of the pieces the dovetail tenons are set out. Two downward cuts with the saw form a dovetail, the wood between the dovetails being removed with a chisel. In like manner, and exactly corresponding in size to the dovetail tenons, the beds into which these tenons fit are set out, and cut with saw and chisel. The two pieces are fastened together, and the corner is made sharp and true. The work under this heading is an introductory exercise to the making of the box described in the next paragraph.



37. Box—its sides joined by dovetailing. Dimensions:—23 × 13·5 × 8 cm. Material:—alder wood. The four sides of the box are first made, then joined as in No. 36. Care must be taken that the dovetails are set out at exactly the same level at all the corners. This is necessary because we have afterwards to separate the upper part of the box from the lower. The sides are next glued together and dressed. The projecting bottom and lid are then cut, their edges moulded, and both glued to the sides. The box is cut open horizontally, so that the cut passes through the middle of dovetails which are on the same level. The top and bottom parts are, lastly, joined by hinges.



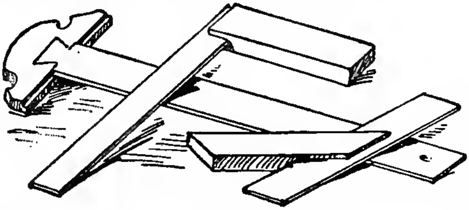
38. Tool-frame. Material:—Scotch fir. Back, 80 × 46 × 1·5 cm. Side-pieces, 80 cm. long, 1·5 cm. thick; breadth at bottom 12, at top 9·5 cm. The two lower horizontal boards, 46 × 12 × 1·5 cm. The top horizontal board, 46 × 9·5 × 1·5 cm.. The framework, consisting of the side-pieces and top and bottom, is joined together by dovetailing; the third horizontal piece is fixed into grooves made in the sides, the front edges of which are curved. The parts of this framework are glued together and the back nailed on to it. Next, strips of wood, 1 cm. thick and 1·5 cm. broad, are prepared, one of their edges being bevelled. These strips are nailed to the back, and serve to support in position the various planes—

trying-plane, smoothing-plane, jack-plane, etc. Similar strips are also nailed on the inside of the top, to prevent the planes from falling forward. To hang up the squares, two right-angled triangles are made, a smaller glued on to a larger; along their vertical edges grooves are cut to hold the squares in place. Lastly, a rest is made for the mortise chisels. It is about 34 cm. long, 4 cm. wide, and 2 cm. thick. Holes may also be made in it to receive the marking-gauge and bradawl. That the tools may hang securely, the upper surface of the rest is hollowed. Its front corners are pared away; and it is fastened with brads to the back of the tool-frame at such a height that the chisels may hang clear of the horizontal board beneath. (For the sake of clearness, the frame is drawn with the side-pieces of the same breadth all the way down, and the curving of their edges is not shown.)

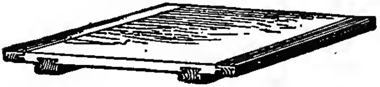
39. Try-square (wooden). Dimensions :—blade, 25 × 3·5 cm. × 4 mm. ; stock, 16 × 3·5 cm. × 4 mm. Material :—maple (or cedar wood, or straight-grained mahogany). The parts being cut, a slit is made in the stock or thicker arm, exactly in the middle and 4 mm. wide. Into this the blade or thinner arm is glued at an angle of 90°.

40. Set bevel. Dimensions :—blade, 32 × 3·5 cm. × 4 mm ; stock, 16 × 3·5 × 1·2 cm. Material :—maple. We proceed as in the case of the try-square ; but the blade is fixed at an angle of 45° with the stock.

41. T-square. Dimensions :—blade, 67 × 4·5 cm. × 3 mm. ; head, 20 × 7 × 1·2 cm. Material :—maple. The joint is the dovetail halving joint. When the two pieces have been



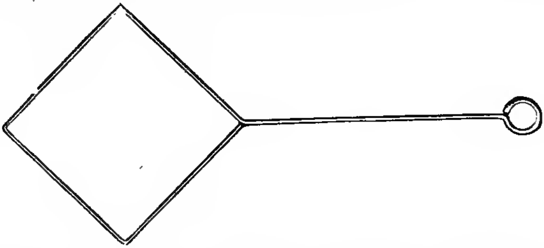
made, a rebate is planed in the head-piece. Then the dovetail on the blade is set out and cut, a bed to receive it being made in the head-piece. The head-piece is bored and curved to the shape shown in the drawing; and lastly, the dovetail is glued into its bed.

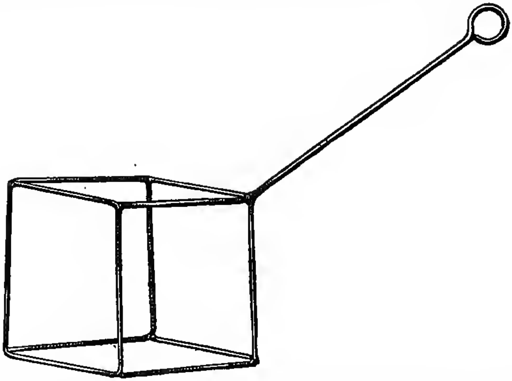


42. Drawing-board. Dimensions:—thickness of wood, 18 mm.; length (including the cleats or end-strips which run across the grain of the board proper), 66 cm.; breadth, 48 cm.; breadth of cleats, 4·5 cm.; rests, 48 cm. long, 18 mm. thick. Material:—Scotch fir. As the drawing-board is fairly broad, it will be found necessary to join two pieces of board together. This may be done, one side of the board having first been dressed by dowelling or by half-lapping, and then fastening together with thin glue. We next plane the cleats and rests, and dress the other side of the board. Then follows the making of the tongues and tenons on the edges of the board, the planing of grooves on the cleats, and the chiselling of mortises through them. The rests are housed in the form of dovetails, they and the cleats are firmly glued, and the whole is then finished with sandpaper.

C. METAL-WORK.

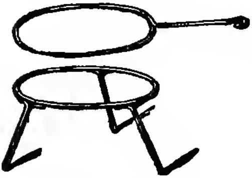
1. Square with looped handle. The first exercises in work with wire yield us frames for producing the thin films by which the cohesion of liquids is exhibited. The frames are dipped in a solution of soap in water. Material:—brass wire, 1·4 mm. thick. Dimensions:—side of square, 6 cm.; total length of wire, 34 cm. Exercise in straightening and bending wire, and in soft soldering. Procedure:—34 cm. of brass wire are cut off with the aid of the triangular file and flat pliers, or better, with the nippers, and straightened by light blows of the riveting hammer, first on a wooden, then on a smooth iron surface. The piece of wire is filed smooth at the ends; then four lengths of 6 cm. are set off with the drawing-point, and the corners of the square are bent with the flat pliers and the thumb of the left hand. The latter must exercise its pressure as close as possible to the pliers, in order that the corners may be sharp and true. The direction of the handle is that of a diagonal produced. Its free end is caught near the bottom with the round pliers and wrapped round one of their jaws so as to form a loop or ring. This loop is placed symmetrically with the handle, there being a sharp corner where loop and handle join. The two ends of the wire are soft-soldered to the adjoining parts, the places where the solder is to be applied being first carefully cleaned.



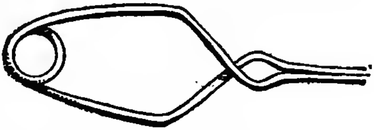


2. Cube. This also serves for experimenting with the films formed by dipping the framework in soap solution. (See Weinhold, *Vorschule*, p. 24 and foll.; English translation, p. 21 and foll.) The material employed is again brass wire—not too thick. The edge of the cube is 5 or 6 cm. If the smaller size be chosen, the work is easier. The cube is composed of four parts. The first part is formed of two adjacent squares bent at right angles to one another, and giving us seven edges of the cube; the second and third parts are formed by two pieces of wire bent at right angles and representing four edges of the cube; the fourth part consists of the looped handle and the wire representing the twelfth edge of the cube. The soldering together of the parts is in this case more difficult.

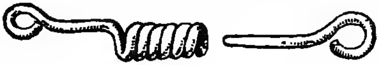
3. **Two wire rings, one with looped handle, the other having three small legs**—also for cohesion experiments. (See Weinhold, *Vorschule*, p. 25 and foll.; English translation, p. 24 and foll.) Both rings are wetted with soap water; one is held horizontally above the other, and between them, by means of a clay pipe, a soap bubble is blown, which attaches itself to the two rings. If the upper ring is slowly lifted, the bubble may be elongated, and forms a cylinder with a spherical surface at either end. By various methods of manipulation, such as are described by Weinhold, a number of interesting forms are produced, which illustrate the tendency of the liquid film to contract. To make the rings, take thin brass wire; the diameter of each may be about 5 cm. The order of procedure is:—straightening the wire; rounding and soldering the rings (the upper one having handle and loop); doubling wire to form each of the three feet; bending the wire at right angles at top on both sides; filing a surface at the places where the feet are to come, so as to give them a better hold on the ring; lastly, soldering the feet on.



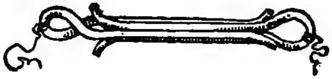
4. Spring clamp—to hold objects which are being soldered or cemented. To make the tongs, we take fairly thick brass wire. The tongs are 13 cm. long and 4·5 cm. wide at their widest part. The wire is first straightened; then the spring is shaped; lastly, the two arms are bent.



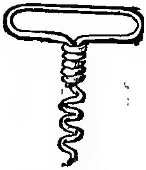
5. Connector for electric wires—spiral. A simple exercise in bending wire, thin and stouter. The spiral part is made from the thin wire, the bolt from the thicker. The little instrument enables us easily to connect wires through which electric currents flow. The connection of the two parts is by the friction of the bolt in the spiral. The length of each part may be 4·5 cm. In constructing, first wind the spiral and bend the loop at the end of it; then straighten the wire for the bolt and make the loop on that.



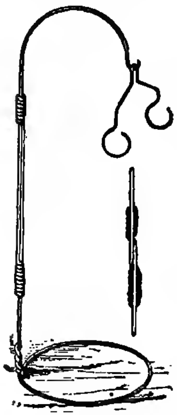
6. Connector—fork-shaped. This serves the same purpose as the preceding object. To make it, we employ moderately thick brass wire; the length of the whole is 6 cm. The wires for the two forks, which are to interlock, are straightened, and then the loops and Y-shaped ends bent.



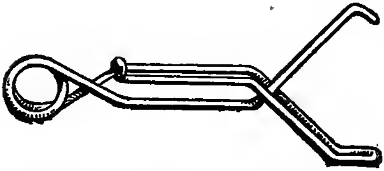
7. Corkscrew. Material:—tinned iron wire. The object is 6 cm. long. In making, first bend the handle, then twist the spiral; lastly, file the point.



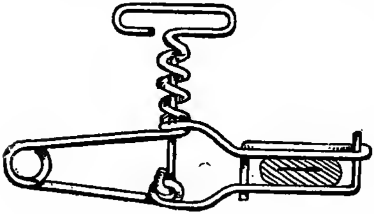
8. Stand, adjustable as to height, with wire bow for holding glass rods. Material:—moderately thick tinned iron wire. Diameter of the circular base, 12·5 cm.; height of the stand, when compressed as far as possible, 33 cm. It may be drawn out to almost twice the height. After straightening the wire, round the base and bend the fixed upright of the stand, this upright terminating in a spiral; then bend the curved upper part. At the lower end of this is a spiral which can be moved up and down the fixed upright; at the other end is a short hook. The wire bow to suspend from the hook is made of a piece of brass wire, which is first straightened, then bent to shape, the loops being formed last of all.



9. **Pinch-cock**—to compress or close rubber tubing. Use fairly strong brass wire. Length, 12 cm.; greatest breadth, 5 cm. The wire is straightened; then the spring obtained by winding the wire; lastly, the holders or handles are shaped.

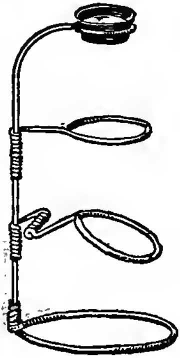


10. **Pinch-cock with spiral acting as screw**—made of tinned iron wire. The wire should be of moderate thickness, the length 9 cm., the height with handle 5 cm. The drawing shows on the right the cross-section of the compressed rubber tubing. The object consists of three parts—the pinch-cock proper, a pin perpendicular to it, and

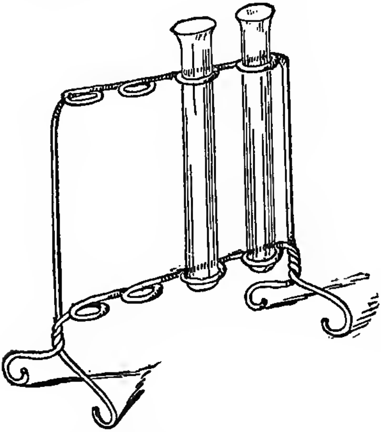


the handle with the spiral. First, the wire is straightened, the spring of the pinch-cock proper twisted, and its two arms shaped. Then we make the pin (vertical in drawing), hooked into an eye in one arm, and passing through an eye formed in the other. Lastly, the handle is made, its spiral winding round the vertical pin, and acting as a screw by means of which the pressure on the tubing may be regulated. The vertical pin is bent at right angles at its outer end, so that the spiral screw may act upon it and draw the pinch-cock together as the handle is turned.

11. Microscope stand. Material:—thin, fairly thick, and thick brass wire. Dimensions:—height, 24 cm.; diameter of base, 8·5 cm.; diameter of ring for slide and ring for reflector, about 5·5 cm.; diameter of ring for magnifier, 3 cm. The whole consists of five pieces — the upright bent over at top to hold the magnifier, the circular base with spiral to close the base and hold the upright, the ring for the magnifier, the ring for the slide, and the ring for the reflector. Of these five parts the first two are of thick wire, the magnifier ring and the reflector ring (the latter with double spiral) of thin wire, the slide ring of the intermediate wire. Order of procedure:—bending loop on upright, winding the spiral at the base, rounding the base-ring, winding the spirals on the other rings, rounding these rings, joining with solder. The slide and reflector may be moved up and down along the upright; the slide can also be made to revolve in its own plane; whilst the reflector may, in addition, be inclined at various angles to the horizontal plane.

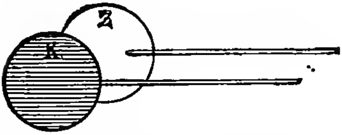


12. Stand for test-tubes. Material:—moderately thick brass wire. Dimensions:—height, 15 cm.; width, 16 cm. The object consists of two parts, one forming the lower part of the holders and one half of the two feet, the other the upper part of the holders, the vertical sides of the stand, and the second half of the feet. In making the stand, the ring-shaped holders in the two supports are first bent on the mandrel; then the parts of the two feet are twisted together; lastly, the open loops at the ends of the feet are bent.

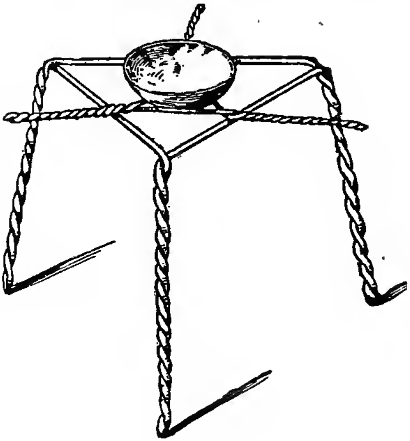


(This and some of the previous exercises are from Hopkins' *Experimental Science*, pp. 678–684.)

13. Zinc and copper discs with handles of copper wire soldered on. If the handles are connected with even a weak electric current, and one disc be placed on the tongue, the other under it, the circuit is completed, and the nerves of taste are affected in a noticeable degree. Material:—copper plate, zinc plate, copper wire. Dimensions:—diameter of discs, 32 mm.; length of the handles, 12 cm. Order in which the work is done:—cut discs, flatten the ends of the handles where they are to lie against the discs, solder these ends to the discs.

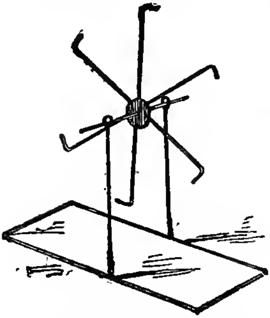


14. Apparatus for Leidenfrost's experiment. The experiment serves to show the effect of applying a small quantity of liquid to a surface which is considerably hotter than the boiling-point of the liquid. The small copper dish is heated to redness, and a few drops of water are applied to it. The water does not hiss, as it would on a moderately hot plate, but lies in a round globule in the dish. As the latter cools, the conversion of the water into steam begins. Material: — thin and thicker tinned iron wire, and copper plate. Dimensions: — length of the feet of the tripod, 7·5 cm.; of a side of the triangle above, 9 cm. The dimensions already given determine those of the small triangle (made of thin iron wire) which is laid upon the tripod. Diameter of copper dish, 3·5 cm. Order of procedure:—The tripod consists of three pieces of thickest tinned iron wire, which are twisted together, two by two, to form the feet, then bent at an angle to form the triangle. The smaller triangle, to rest on the larger, is made from three shorter pieces of thin iron wire, twisted as before but without the angular bend. Last of all, from a piece of copper plate a disc of suitable size is cut, then punched into the form of a dish.

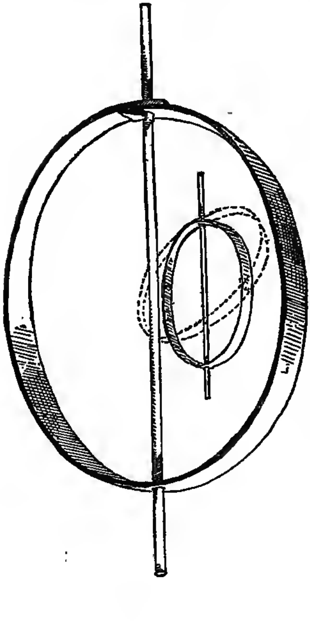


15. Electric wheel. Insulated and electrified, the wheel revolves. In constructing it, we employ thin brass wire and tin plate for the wheel; for the framework, thin iron wire. Height of frame, 7·5 cm.; quadrilateral base, 11 × 3·5 cm.; diameter of wheel, 10 cm.

The framework is formed by bending and intertwining two pieces of wire; the uprights are looped at the end to support the axle. The spokes of the wheels are made, bent at a right angle at one end, and flattened at the other, where they are to lie on the disc. The latter is cut from tin plate, a hole being drilled in the middle, and the axle passed through. Axle and spokes are joined to the central disc with soft solder.

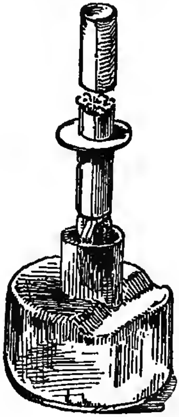


16. Centrifugal ring. To show the effect of rotation in flattening, the axle is turned rapidly between the fingers. (See the small inner drawing.) From being circular, the ring becomes elliptical, thus exhibiting the effect of centrifugal force. The spindle is a straightened piece of brass wire, 25 cm. long, 3·5 mm. thick. The ring, 50 cm. long, 12 mm. broad, is cut from a plate of brass, 0·4 mm. thick, and hammered on the anvil with a flat hammer to the hardness of a spring. The blows must be regular and directly vertical. At the two ends and in the middle, holes are punched,



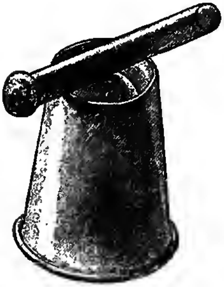
the middle one being made somewhat larger, so that the spindle may pass loosely through it. Those at the end, on the other hand, just admit the spindle, which is here soldered to the ring.

17. Cubic decimetre—of zinc plate. On a piece of zinc plate, 10 cm. wide and, say, 0·8 mm. thick, set off, to obtain the sides, four times 10·15 cm.; draw lines at right angles to the edges and joining the points of division, cut accurately along these lines; straighten out with the hammer the pieces so obtained. Next set off the exact breadth, 10 cm., on each piece, and on each of the edges (1·5 mm. broad) then left over, solder a side with one of its 10 cm. long edges in a vertical direction, so that it starts from the 10 cm. mark. The bottom is cut rather larger than the area it is to cover, and is soldered on outside all round. The space inside the vessel thus made is equal to a cube of 10 cm. edge. The zinc that projects outwards and the superfluous solder are filed away, the cube being then polished with dry emery paper.



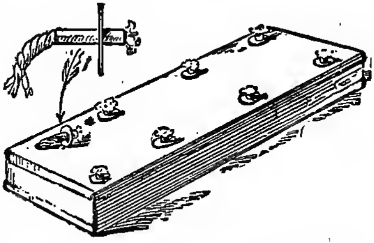
18. Spirit lamp. An empty ink-bottle will serve to make the spirit-holder. The socket for the wick and the extinguisher are of tin. Dimensions:—total length, 6 cm.; diameter of the larger disc, 2·5 cm.; of the smaller, 1·1 cm.; of the wick socket, 1·1 cm.; of the extinguisher, 1·5 cm. We cut the metal for the sockets, and round on a mandrel, then solder. Lastly, we cut the two discs, soldering one to form the top of the extinguisher, the other round the lamp socket.

19. Flower spray. Material: — zinc plate, 0·5 mm. thick. The jacket is planned by describing two circles (of radius 210 mm. and 136 mm. respectively) and making an angular opening of 56·5° (longest chord, 200 mm.). The plate having been cut according to the drawing thus obtained, the ends are brought together in an overlapped join. The truncated cone resulting has approximately the following dimensions:—at top 44 mm., at bottom 67 mm.; height, 72 mm. With the narrow part of the hammer the bottom is beaten out on the edge of the anvil, or on a piece of flat iron fixed in a vice, to a breadth of 2·5 mm. in a horizontal direction. The bottom is made 77 mm. in diameter, and as the beaten-out rim is 72 mm. in diameter, the bottom extends beyond the rim 2·5 mm. all round. The edge of the bottom is first turned up, then beaten down on to the projecting rim of the jacket. The double rim is lastly laid on anvil or flat iron and hammered on the under side. To prevent leakage, solder.

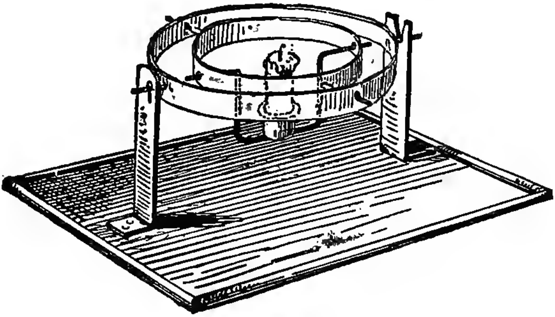


In the thick tube, 11 cm. long, 12 mm. in diameter, made by rolling zinc plate on the mandrel, we make a hole. This opening, 12 × 4 mm., is cut with a small chisel 4 cm. from the front end of the tube and on the join. Through the opening is passed a bent brass tube (11 cm. long, 4 mm. in diameter), which is soldered in. To bend this tube, we first heat it till it glows faintly, then quickly cool it in water. The effect is to render it soft. If we bend it carefully with the fingers, there is no need to fill it first with lead or resin, as is usually done with thicker tubing to prevent the pipe from crushing. The thick tube is closed with a cap, which is soldered on, and has a hole punched through the centre. The opening of this cap, through which the thin tube projects a little (0·3 mm.), leaves about the latter a free concentric space of about 0·5 mm. breadth. The thick tube is soldered across the vessel; the lower arm of the thin one reaches almost to the bottom. If we blow through the thick tube, the current of air issuing from the front draws water up into the thin tube and breaks it into spray.

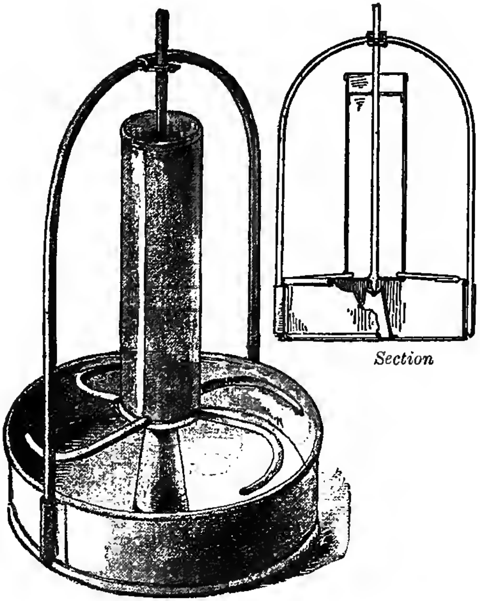
20. Larger spirit lamp—for the expansion apparatus. (See Bench-Work, No. 17; Metal-Work, No. 28; Glass-Work, No. 1.) The heat by which the metals are expanded is not so well applied by a simple spirit lamp of the ordinary kind as by one which has a row of burners, and is therefore better calculated to heat the metal bars evenly. We may construct it of tin plate in the dimensions of 25 × 9 × 3 cm. When the parts have been cut, we first bend the frame for the side-walls from a single piece of tin plate, and solder the two ends together. Top and bottom are next bent, eight holes punched through the former, and then both soldered to the frame already made. From a piece of brass tubing of sufficient width we cut eight sockets, each 2 cm. long, for the wicks. Lastly, discs are cut from brass plate to support the sockets, holes are bored in the discs to correspond in diameter to the sockets, which are soldered firmly in.



21. Ship's lamp. Lamps, compasses, etc., in ships are always suspended so that one of the axes on which they turn is in the direction of the ship's length, the other at right angles to the first. The object is that the condition of stable equilibrium may be maintained no matter how the ship oscillates. For the base we use either wood or iron plate (dimensions:—23 × 11 cm.); for the supporters, hoop iron; for the rings, zinc plate; and for the axes, tinned iron wire. The dimensions of the supporters are:—height, 12 cm.; breadth, 2 cm.; thickness, 1·5 mm. The diameter of the outer ring is 14 cm.; that of the inner, 10 cm. The candle socket is 2·5 cm. high and 24 mm. in diameter. Order of procedure:—The base, if of iron plate, is cut and bordered, and wire is let in round the border. The projection of the border is upwards. The object of the bordering is to give rigidity to the plate. Next the hoop iron for the supporters is bent at right angles; holes are bored through the feet, the resting-places for the axes filed in; the supporters riveted to the base. Then follows the cutting, bending, and soldering of the rings, and the soldering of the axes into them. Lastly, the wire bow to support the socket is bent, and the socket cut, rounded, and soldered to this bow.



22. Segner's water-wheel. Of zinc plate, 0·5 mm. thick. The side of the lower vessel (which is 19 cm. in diameter) is cut 60 × 6 cm. A half-round rim is made on this side as follows:—The strip together with a piece of flat iron, 3 mm. thick and filed half round on its upper edge, is fastened in the vice so that the zinc rises 5 mm. above the iron; the upstanding part is beaten with the wood hammer over the rounded edge of the iron. We then place a wire (2 mm. thick) in the groove thus formed, secure it at several points by gripping with the pincers, and complete the rolling of the rim by means of blows of the hammer (directed from without and above). The rim (5 mm. broad) of the bottom of the vessel is bordered. The jacket of the long cylinder (18 × 18 cm.) is first bordered at the top, and then rounded. The bottom (64 mm. in diameter) of this cylinder is likewise bordered. At one end of each of the four outflow pipes (9 cm. long, made of 4 mm. brass tubing) a wedge-shaped piece is filed out, the metal is then brought together and soldered, a wire being inserted so as to prevent closing. The pipes when bent are soldered into four holes made at the bottom of the cylinder. The axis of the cylinder is of iron wire (24 cm. long and 4 mm. thick); it ends in a short point, is firmly soldered into the bottom of the clyinder, and is kept in place at the top by a bridge (1 cm. wide) fixed inside the cylinder. The point of the axis turns on a disc of brass (1·7 mm. thick), with a hole sunk in the centre. This disc rests on a truncated cone (for



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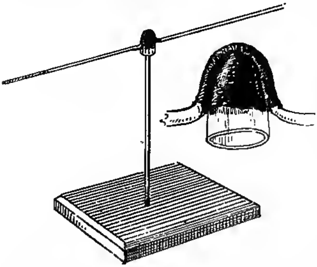
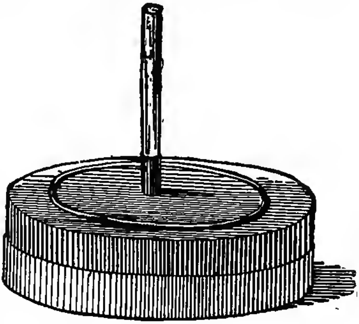
jacket take radii of 5 and 10 cm.; greatest chord, 9 cm.), which is soldered in the middle of the large vessel.—The iron bow (68 cm. long, 4 mm. thick) supports at the top a small rolled brass plate with a hole to guide the axis. Below the ends of the bow fit into two metal sockets. The pieces of metal (50 × 25 mm.) to form these are rounded out in the middle, the ends being bent horizontally. Lastly, the sockets are soldered on to the outside of the vessel.

23. Simple magnetic needle balanced on pivot. (See Glass-Work, No. 19.) The base is either of wood planed or of brass plate made in disc form. In the latter case cut the disc 7 cm. in diameter, and hammer the edges. The pivot stand is 10 cm. high, is of steel wire, is brought to a point, but not a sharp one, and is soldered into the base. The magnetic needle, also of steel wire (20 cm. long), is best bent when at a red heat. Last of all, we cement the glass cap (see Glass-Work, No. 19) with sealing-wax into the bend.

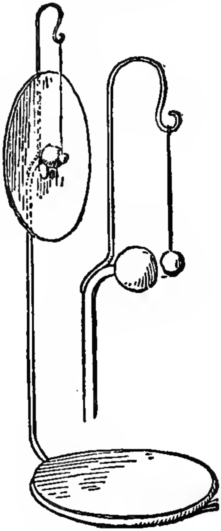


24. Metal parts for the Differentialrolle. (See Cardboard-Work, No. 20; Bench-Work, No. 22.) Material:—brass tubing and brass plate for the weight; thin brass wire for the hook, thick for the supporter. Dimensions:—height of cylinder representing the weight, 5 cm.; diameter, 1 cm.; supporter, 7 cm. long. Order of procedure:—cut brass tubing; fit in bottom and solder; bend hook for weight; fill in latter with lead so that the hook is also held; file grooves in the supporter, one in the middle for the weight, and one at each end for the strings.

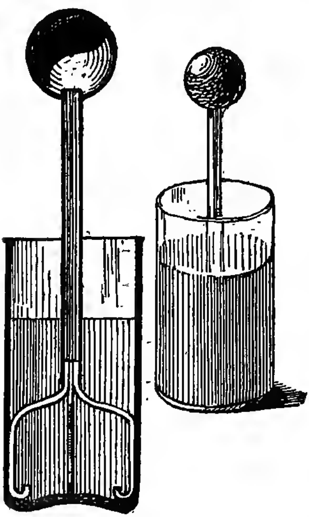
25. The Electrophorus. (See Glass-Work, No. 13.) The electrophorus is an arrangement for generating in a simple manner a considerable supply of electricity. For the conducting support we take either a *form* made of tin plate and a cake of resin lying on it (for construction, see Weinhold, *Vorschule*, p. 375; English edition, p. 578 and foll.), or a disc of ebonite, which can be electrified by flapping with a piece of fur. The cover is made with brass plate, brass wire, brass tubing, and a glass rod. The diameter of the cover may be 14 cm.; the height of the brass socket for the glass handle, 2 cm. The cover is cut and made as level as possible, then a rim is formed round it by bending the edge all round over a stout wire. In the middle of the cover we solder the socket, and into it insert the insulating glass rod which is to serve as a handle.



26. Pendulum for the gradual discharge of electricity. Let us imagine this simple apparatus placed in front of a conductor. The pith ball which hangs from it is attracted by the conductor, charged with electricity, and then repelled. The ball gives off its electricity to the brass knob on the apparatus, which discharges it. The process is repeated: the pith ball is again attracted, charged, repelled, and again gives off its electricity to the brass knob. Moving to and fro like a pendulum, the pith ball can thus discharge the whole store of electricity in the conductor.



To make the apparatus, we employ brass plate, thin and fairly thick brass wire. Dimensions:—diameter of base, 14 cm.; total height, 32 cm.; height of the brass knob above the foot, 21 cm. First, the thicker brass wire is cut to form the stand proper, and bent at the bottom into a circular ring, 14 cm. in diameter. At its top the stand proper is bent over so that the brass knob at the end of it is vertically above the centre of the ring. We next cut the brass disc for the foot, and solder it on to the wire ring already bent. To form the brass knob, we cut from brass plate a circular disc, punch it round, fill with lead, and solder to the stand. This done, we bend from thin brass wire the upper support for the pendulum, making a hook at one end and an angle at the other. This upper support is soldered firmly to the stand. To complete the apparatus, we need a pith ball fastened on a silk thread, and a cardboard disc to make the pendulum stand out clearly, so that it may be seen by the class during the lesson.



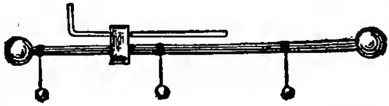
27. Leyden jar. (See Glass-Work, No. 12.) This is a condenser which serves to accumulate a large quantity of electricity. A large cylindrical glass vessel is coated to near the top both inside and outside—bottom included—with tinfoil. The foil is best attached with glue. The materials for the other parts are brass plate, brass tubing, and moderately thick brass wire. The total height of the brass rod standing in the jar is 20 cm.; the area to be occupied by the three binding feet is determined by the size of the jar. In making, cut the three feet from moderately thick brass wire; bend loops at the bottom of them, and shape them as shown in the drawing. Then cut brass tubing of the thickness of a pencil for the upright, and into one end of this solder the three feet already bent. Lastly, cut two round discs from brass plate, punch them to hemispheres, solder together, and then solder the sphere thus obtained on to the upright.

28. Metal parts for the expansion apparatus. (See Bench-Work, No. 17; Metal-Work, No. 20; Glass-Work, No. 1.) We cut two bars, one from bar iron, the other from bar brass, and file the end surfaces true. In like manner, towards the ends of the two bars, at the place where they rest on the lower support, we file flat surfaces on the round bars, that there may be more contact between the latter and the index wire which turns as the metals expand. After the filing the bars are polished with emery powder. Their round ends are thrust into the holes bored for them in the higher side-piece till they press on the wood, so that they cannot expand in this direction. The other ends near which the flat surfaces have been filed rest on the lower side-piece,' upon which to reduce to a minimum the friction of the index wires a small sheet of glass has been fastened with sealing-wax. The index wires may be made as follows:—To lie between the glass and the bars, we use common steel needles; through the eye of each a thin aluminium wire is passed, and secured with sealing-wax in such a way that only a short end projects below, whilst a long index finger describing a large arc rises above. A small ball of sealing-wax fastened at the short end maintains equilibrium. Instead of the wire, dry straws can be used. Besides the bars of iron and brass, we may also make similar bars of lead, copper, and zinc, to show the expansion of different metals. These may be used two at a time, and the several expansions noted.

29. Metal parts for the retort-holder. (See Bench-Work, No. 28.) For the ring (diameter, 7 cm.; the whole stand is 22 cm. long), we employ fairly thick brass wire. The work, involving only the bending of thickish wire, presents little difficulty.—For the spring holdfast or gripper to hold test-tubes, we need in the first place a straight piece (30 cm. long) of very thick brass wire. The actual gripper (diameter, 3 cm.; width, 2 cm.) is cut in two halves, from thin brass plate, and the pieces bent round. The construction of the holdfast is seen from the special drawing. On one half is bent a round socket, by means of which, at a later stage, the holdfast is fitted on to a holder made from the thick brass wire and soldered to it. The end of the other half is left flat, and serves as a catch for opening the holdfast. At the sides of the two halves small lappets are bent and holes bored in them. These lappets are intended for the bolt, which with them forms the hinge. We now twist from thin steel wire the spiral spring which is to press the jaws of the holdfast together, and join the two halves together with a bolt, against which the spring is thrust. The last step is to solder the holdfast on to the thick wire holder.

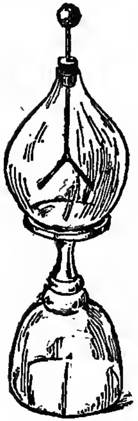
30. Lightning tube—to produce a succession of sparks in darkness. (See Glass-Work, No. 14.) To make the metal parts, we need brass tubing, plate brass, and brass wire. The diameter of the glass tube determines that of the hoops. The length from the bottom of the upper hoop to the top of the knob is 10 cm. In constructing the apparatus, we first cut the brass tubing for the two hoops. From brass plate two discs are cut to serve as caps for the hoops, and soldered on to them. For the knob, we cut two discs from brass plate, punch them into hemispheres, and solder them together. The straight wire is next cut and soldered into the knob. Lastly, a hole is drilled in the cap of the upper hoop; the wire is filed down to fit this hole, and is soldered into the cap. The hoops with caps can now be applied to the glass tube.

31. Apparatus for experiment on electric induction. (See Glass-Work, No. 17.) If an electrified rod of ebonite be brought near an insulated, rod-shaped conductor on which pith balls are hung by threads, the farther end of the conductor will be electrified with like, the nearer with unlike electricity, whilst the middle is non-electric.



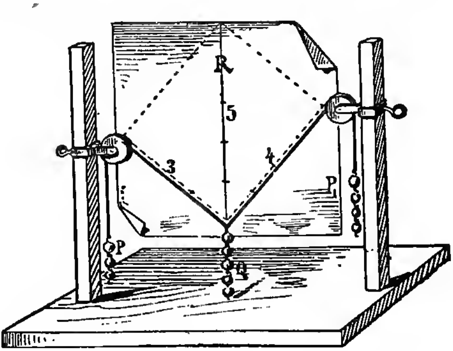
In making the apparatus, we use bar iron and brass plate. The length of the rod, including the two knobs, is 32 cm. The iron rod is cut and polished with emery powder. Tenons are cut on its two ends. Four discs for the two knobs are next cut and punched into hemispherical form. Holes are made in two of the discs, which then by means of the tenons are riveted on to the rod. Lastly, the other halves of the spheres are soldered to the halves already riveted on. The vulcanised indiarubber rings from which the pith balls are suspended are small sections of tubing.

32. The Electroscope—a simple apparatus to indicate the presence of electricity. (See Glass-Work, No. 15.) An inverted wine-glass serves as a support. To the foot of this we cement with sealing-wax the vessel in which the electroscope is contained—a short-necked flask, which preserves the leaves within from damp and draughts. The flask is closed with a cork, through which passes a brass rod, having at the top a knob and at the bottom the leaves. The length of the rod with the knob included is 8 cm. To make the metal parts of the electroscope, we cut the brass wire for the rod, file it at the bottom to an edge (see Weinhold, fig. 307, C), and solder to the bottom a thin wire, intended to support the leaves. For the latter aluminium leaf will be most suitable, because aluminium has a lower specific gravity than gold, and the leaves accordingly need not be so thin. The leaves cut, a hole is made through them at one end, and they are thus attached to the thin wire just mentioned. The upper end of the brass rod is bent into the form of a hook, and introduced into a bullet mould, when lead is poured round it. The bullet or knob thus made must have its surface carefully smoothed with a sharp knife. To insulate the brass rod properly, it is not passed directly through the cork, but through a piece of thin glass tubing inserted in the cork. The brass rod is cemented into the glass tubing by means of sealing-wax.



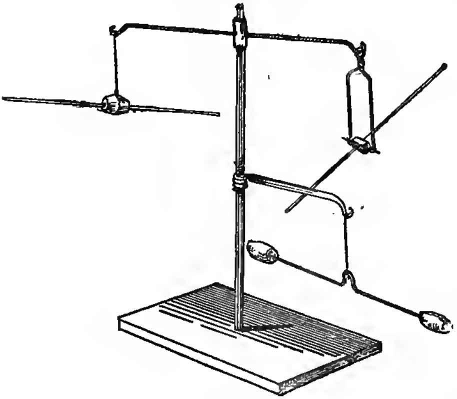
33. Roller for the refraction of light apparatus. (See Bench-Work, Nos. 31a and 31b; Glass-Work, No. 2.) Length of axle, 5·5 cm.; diameter of two discs, 2·5 cm. The axle is of round iron, the two discs made from stout brass plate. The former is cut first; tenons are made on its ends, and on these screws cut. Next the discs are shaped, holes drilled in their centres, and the female screws threaded in these holes. Lastly, the discs are polished with emery powder and fitted on to the axle.

34. Metal parts for the parallelogram of forces apparatus. (See Bench-Work, No. 21.) The material required is brass plate, thin and thicker brass wire, and lead for the weights. These weights are leaden bullets made in a mould, a thin brass wire being inserted and held by the metal as it cools. This wire is afterwards bent into a hook or into a ring. The dimensions of the blocks for the pulleys depend on the thickness of the wooden uprights. The blocks are cut each in one piece, which is bent on a quadrangular shape. Between the arms of each block is soldered in a piece of brass of a size which depends on the thickness of the pulleys. In order to enable the blocks to be moved up and down the uprights at will, and fixed at any desired height, holes are bored in them, and in these holes female screws cut. The corresponding screws are threaded on screw-hooks, bent from thick brass wire. To prevent these screw-hooks boring into the wooden uprights when the screw is turned, we place between them and the wood within the blocks rectangular shields, cut from thin brass plate, and having their edges so bent round that they move up and down with the blocks. The pulleys are of hard wood, and best procured from a turner's. The apparatus furnishes us with a statical demonstration of the parallelogram of forces. The weights P and P_1 represent the two forces; the weight Q, which keeps them in equilibrium, represents the magnitude of the resultant. The side-lines of the parallelogram represent P and P_1; the diagonal, Q.

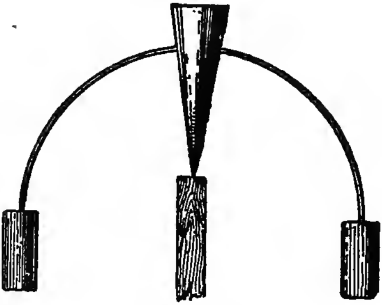


35. Metal parts for the inclined plane. (See Bench-Work, No. 27.) The necessary materials are lead, brass plate, and brass wire. The pulley has a diameter of 4·8 cm., and is 2·4 cm. thick; the disc for the scale-pan is 6·5 cm. in diameter. The pulley may be cast from lead, the axle being held by the metal as it cools. Next, the frame about the roller is cut from brass plate, bent, and holes drilled in it, at the proper places, for the axle of the roller and for a ring or eye. This eye is bent and riveted into the frame, and the latter, when the roller has been fixed with its axle in the holes, is soldered together. Lastly, the disc for the scale-pan is cut from brass plate and hammered hollow to receive the weight.

36. Stand for various purposes—with declination and inclination needles, and with a glass arm for insulating. (See Glass - Work, No. 18.) As a base we take either a wooden board or a piece of iron plate; if the latter, it is bordered. The following materials will also be required: round iron, brass, plate, thin and thicker brass wire, as well as tinned iron wire and steel needles. Dimensions:—base, 20 × 15 cm.; height, 40 cm.; length of the two wire arms, 11 cm. each way from the middle. If we make the base of iron plate, we should begin our work by cutting it and making the border; we then cut the upright from round iron, polish it smooth, make a tenon on it, and rivet it with this into the base. The next step is to cut the brass socket for the double arm shown at the top of the stand, and to round this socket on a mandrel. It is left open at one side; acting as a spring, it grips the upright firmly, and with the two arms attached can be moved up and down. These arms are cut from the thicker brass wire; a hook is bent on each at one end, the other being soldered into the socket with

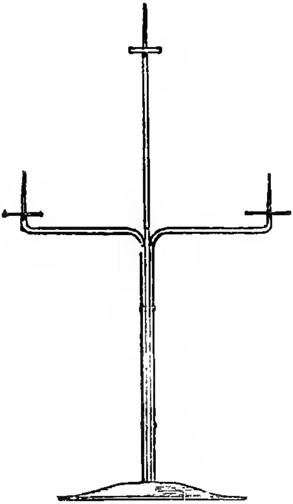


hard solder. To the left in our drawing a magnetic needle is suspended by a thread, the needle being passed through a cork specially cut. To the right there is an inclination needle, the pendant support of which is bent of thin brass wire. As an axis we take two small sewing-needles, which are thrust through the loops on the pendant support into a cork. This cork is pierced with a long magnetised knitting-needle, which, hanging freely as to dip, forms an inclination needle. The insulating glass arm consists of a glass tube, and is fastened in its place by means of a piece of tinned iron wire. This wire is at one end twisted in spiral form round the upright, at the other thrust into the glass tube and secured with sealing-wax. By means of the spiral the insulator may be moved up and down at pleasure. The glass tube for the arm is first drawn out at one end and bent into a hook. In our drawing there is seen insulated a thin wire, bent in the middle and having a pith ball at either end.



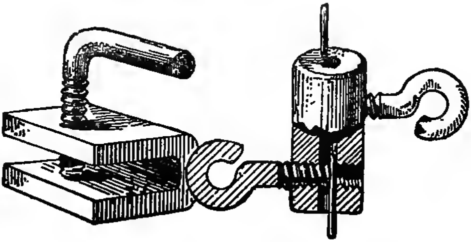
37. Centre of gravity apparatus—to exhibit the condition of stable equilibrium in bodies *apparently* supported at a point below the centre of gravity. In making the apparatus, we employ:—brass tubing for the weights (which are filled in with lead), brass plate for the hollow cone, brass wire, square bar iron for the supporting pillar, and iron plate for the base. Dimensions :—base (not shown), 10 cm. square; height of pillar, 12·5 cm.; of the cone, 12·5 cm. Cut the iron plate for the base and border it; then cut the supporting pillar from square bar iron, make a tenon on it, and rivet this into the base. Next cut the cone and round it. To allow the wire bow to pass through, holes are punched in the jacket of the cone; then the latter is soldered together so that the apex is somewhat blunt. Cut the wire for the bow; bend it, and solder it into the cone. Lastly, make the side weights of brass tubing; cut bottoms for them and solder on. Fill with molten lead, so that the metal as it cools holds the ends of the wire bow.

38. Candlestick for experiments with concave mirror and lenses. The candlestick is made of iron plate and hoop iron. Dimensions:—diameter of base, 11·5 cm.; height of candlestick, 30 cm.; breadth, 13 cm.; difference in height between the upper and the two lower candleholders, 11·5 cm.; breadth of the hoop iron, 1·3 cm.; thickness of the same, 2·5 mm. In making, we first cut the three pieces of hoop iron of which the candlestick consists, and bend the two outer ones rectangularly in the vice. Then punch the holes for the rivets which are afterwards to join the three pieces into one, and file the ends into spike shape to receive the candles. Now rivet the three pieces together and make a tenon at the bottom. To make the foot, cut a disc of iron plate, hammer it concave, cut the hole for the tenon, and rivet the latter into the foot. Lastly, cut three small discs (diameter, 2·5 cm.) of iron plate, make holes in them, and fit them on to the iron spikes.



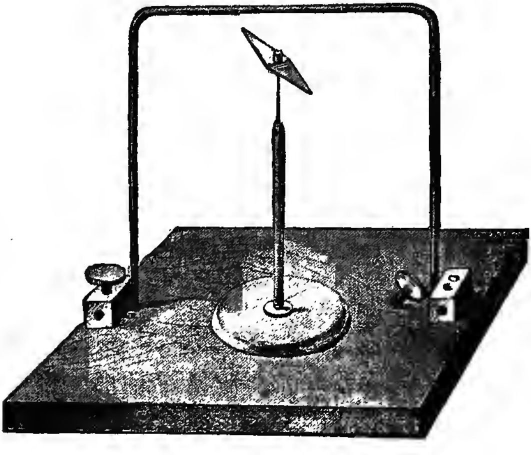
39. Fixed and movable pulleys. (See Bench-Work, No. 7.) The two pulleys can be applied equally well to the same side of the upright, and the whole apparatus except the grooved wheels (best obtained from the turner), of hard wood, can be made of metal. In that case we need for the base, iron plate; for the upright, squared bar iron; for the supporters, iron wire; for the weights, brass tubing and brass plate. Dimensions:—base, 18 × 12 cm.; height of the upright, 30 cm.; cross-section, 1·5 cm. square. Order:—First the plate for the base is cut, and the edge strongly hammered to make the base rigid. Then the squared bar iron is cut for the upright, a tenon is made at the bottom, holes are drilled to enable us to apply the pulleys (the grooved wheels), and the upright is riveted into the base. The supporters are made by twisting two wires together, bending them at right angles, and riveting them into the holes already drilled in the uprights. For the weights we cut brass tubing, and discs of brass plate for their bottoms. Fill with molten lead, so that, as before, a handle of brass wire is gripped by the cooling metal.

40. Binding screws—two kinds of. (See Weinhold, *Vorschule der Experimentalphysik*, p. 423; English translation, p. 657.) For the first we need thick sheet brass and brass wire. A piece of sheet brass of the requisite size is cut, filed straight, and bent round a piece of flat iron. In one arm we drill a hole and cut in it a hollow screw. To make the screw to fit into this, a piece of brass wire is bent at right angles and a screw cut on one of its arms.



The second kind of binding-screw is for connecting wires to establish an electric circuit. To make it, we need a strong cylinder of brass and brass wire. From the cylindrical bar of brass we cut with the saw a piece of suitable length, and bore therein four holes, two for the wires and two for the screws, which enter from the sides. In the two latter holes hollow screws are cut. We next bend two hooks, cut screws at their straight ends, file the whole clean, and finish.

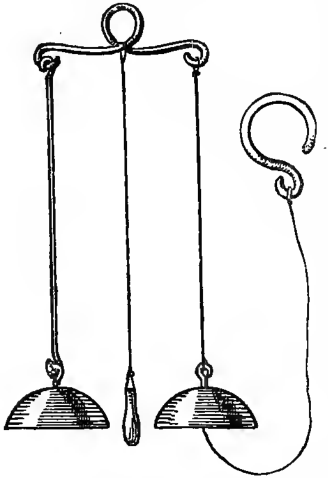
41. Magnetic needle balanced on pivot-stand, with binding screws and wire arch. The magnetic needle, 8 cm. long, 1 cm. broad, made from a steel plate 0·6 mm. thick,



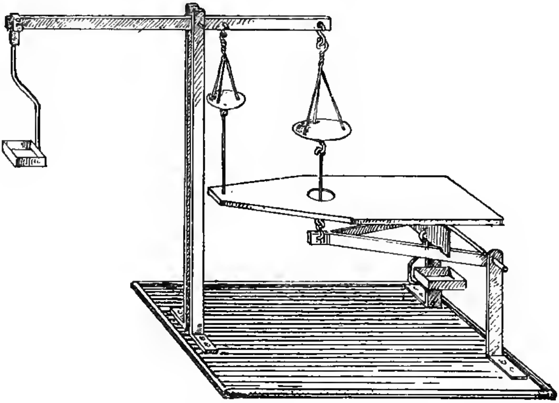
has in the middle a small cap, thrust through a hole and riveted in. This cap is made from a piece of brass wire, 5 mm. long, 3·5 mm. thick, in which a hole 4 mm. deep, 2 mm. wide, is drilled. The rim of the foot of the stand (foot cut from brass plate 0·65 mm. thick, diameter 56 mm.) is curved downwards on a bordering iron with rounded edge, and hammered true on the big punch, which is fixed in the vice; then the cut edge is filed level. To obtain a better hold of the foot whilst polishing with emery, we solder to it on the inside a metal handle. It is now turned in the hollow of the hand with oiled emery-paper, thus acquiring a circular *grain*, as it were. The brass upright (6 cm. high, 3·5 mm. thick) is provided at the bottom with a $\frac{1}{8}$ inch screw, passed through the foot and secured with a nut made from brass plate 1·7 mm. thick. This nut, which is rectangular, is not visible in the drawing. In the top of the upright a hole is made, into which a needle is soldered, and serves as a pivot on which the magnetic needle may be balanced.

The binding-screws (18 mm. long) are sawed from quadrangular brass wire (8 × 8 mm.), the cut surfaces being filed true. 6 and 12 mm. from the front edge we drill two vertical holes right through the wire, and a similar hole horizontally in the front surface to a depth of about 10 mm. In the horizontal hole in each part a $\frac{1}{8}$ inch female screw is threaded. The screws to fit are of brass wire, 3·5 mm. thick; on them are riveted and soldered discs of metal, 14 mm. in diameter, and having milled edges. By means of wood screws, which go through the *back* vertical holes, the binding screws are fastened to a varnished alder board (16 × 13 × 1 cm.). The wire arch (brass or copper wire, 40 cm. long, 1·7 mm. thick) is bent in fork shape at the ends; the fork points are fixed in the wood; the wood screws passing between the prongs secures the arch as well as the binding-screws to the board. (*Bericht der Lehrerbildungsanstalt für Knabenhandarbeit*, 1891.)

42. Peal of electric bells. Material:—brass plate, thick and thin brass wire. Dimensions:—width of the curved upper piece, 8 cm. Order:—bend first the wire for the upper piece, making a large loop in the middle, a smaller one at each end. The bells are made by cutting discs (6·5 cm. in diameter), beating them concave, and then polishing them. Holes are made in the bells to enable us to suspend them. The bell shown in the drawing on the right is insulated by being hung on a silk thread; it can be brought into connection with a conductor by means of a silver thread, or of a short chain simply made with links of brass wire, the links ending at either end in a hook. Through the hole in the bell there is a short wire also terminating both above and below in a hook; we are thus able to attach the bell to the silk thread and also to the chain. The other bell is not insulated, but its electricity is conducted off to the earth. Thus it hangs on a brass wire bent at top and bottom into a hook, and at the bottom catches in a hook on the bell. The slapper hangs insulated on a silk thread; the hammer part is cut from thick brass wire, filed to shape, and having a hole bored through its upper end. If electricity be conducted to the right-hand bell, it attracts the clapper, and is communicated to it; hence the clapper, being charged with like electricity, is repelled. The clapper swings to the other bell, and discharges its electricity into it, with the natural consequence that the electricity is conducted to the earth with which the left-hand bell is connected. The clapper having thus become non-electric, the same process is repeated.



43. Weighing machine. Material:—iron plate, hoop iron for the framework and the beam, zinc plate, brass plate, iron wire, brass wire. The base (27 × 15 cm.) is made of iron plate. To give it stability, its four edges are bent at right angles, so that sides are formed to the plate constituting the base. The hoop iron employed is 13 mm. wide and 2·5 mm. thick; the upright is 30 cm. high; the two low supports are 8 cm. high; the beam has a length of 30 cm. The upright consists of two strips of hoop iron; in these when they have been cut we punch holes for the rivets and axle of the beam; the feet are then bent at right angles and the strips riveted together above. In like manner we make the two low supports for the scale; but in one of them there is—not a hole—but a slit narrowing towards the top and enabling us to lay an axle easily in position. Upright and supports finished, we punch holes in the base, and so can

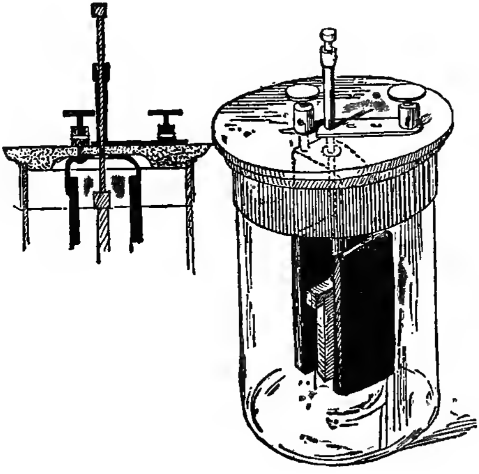


rivet the four pieces in their places. Next comes the making of the weighing-beam. It consists of three parts, a long middle part and two shorter parts, which are only one-third as long as the middle part. These two pieces together form the shorter beam (in the drawing, the one to the right), and are joined together by means of rivets. Holes for the weight-pans and for the axle are then bored through the beam. We now make the weight-pan to the left of zinc plate, 5 cm. square, the rim 5 mm. high. To suspend it, we bend a piece of iron wire into the shape to be seen in the drawing; on the top of this wire we bend a hook; at the bottom we bend at right angles, hammer flat, and solder on the weight-pan. We further need for the suspension of the pan a claw, 12 mm. wide, 5 cm. long, bent over the beam and riveted to it, whilst below the beam the fork is pierced to admit an axle, on which finally the hook of the iron wire is hung. The two round weight-pans, those to the right in the drawing) are next cut from brass plate (diameters, 2·5 cm. and 4·5 cm.), and hammered somewhat concave; through the edges at equal intervals three holes are punched, as also a hole in the middle. To suspend each of the pans, three wires are used, one set each 9·5, the other set each 11 cm. long. The three are twisted together at the top, formed into a hook, and so attached to the beam; at the bottom each is passed through a hole in the pan and secured by a loop underneath. In the middle holes of the pans small brass-wire hooks are riveted, and in each of these hooks again hangs a piece of wire terminating in its turn in a hook.

It is now time to make the lower weighing-beam. This is done with hoop iron 12·5 cm. Taking a piece of hoop iron, 25 cm. long, 13 mm. broad, but only 1·5 mm. thick, we bend it together in the middle, and then, 1·5 cm. from the bending-point, draw it apart into an acute angle. A hole is drilled in the double end so as to allow the beam to be connected with the larger of the two weight-pans above; through the divergent ends holes are also drilled, a straight iron rod thrust through these holes and laid as an axle in the two low supports of the scale. The scale or large weighing surface (24 × 10 cm.) is cut from zinc plate, sloped away towards the side where the upright is, the edge bent at right angles all round to a width of 5 mm., the corners soldered. To let the wires through which hang down from the circular weight-pans, there must be made through the scale a small hole, and more towards the middle a larger one. — We must next make a blade of tin plate, 9 cm. long and

3 cm. broad; 1 cm. of the breadth is bent over at a right angle and soldered on to the under side of the scale. On the same side two small tin-plate strips are fixed, serving as supports for a piece of iron which can be thrust backwards and forwards and produce equilibrium. In the knife hangs, lastly, another weight-pan. We cut it (5 cm. square) from zinc plate, and bend up the edges 5 mm. all round. We next bend a piece of iron wire to suspend this weight-pan. At the top there is a hook; at the bottom we bend, as before, at a right angle, flatten, and solder the weight-pan on. The upper hook is fixed in a hole in the knife.

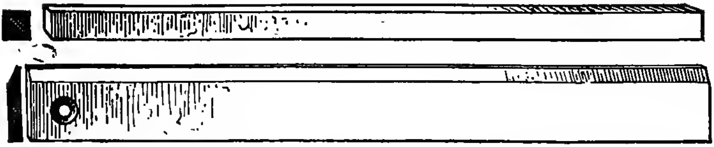
44. Element of chromic acid battery. (See Glass-Work, No. 16; and, for cover, Bench-Work, No. 25.) We



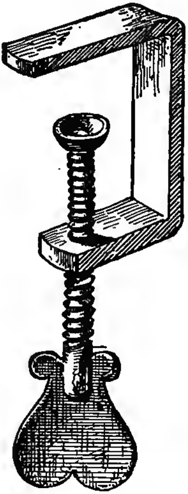
use a glass bottle the top of which has been sprung off; about the upper edge we lay a strip of brass 2 cm. wide, cut from thin brass plate, bent round, and soldered together at the ends. On the under side of the wooden cover is a strip of thin copper plate (see section). This is cut 25 mm. wide, and bent to shape. It then has five holes made in it; a larger one in the middle and four smaller ones at the corners, the latter to screw it on to the cover. At the end of each bent arm of the copper strip two other holes are made; these are to enable us to rivet the carbon on. The carbon, however, cannot be riveted directly to the copper strip, but two leaves of thin plate are laid on either side of each carbon block and the latter is riveted in between them to the copper strip. The binding-screw to the left in our drawing is driven through both the wooden cover and the copper strip, then riveted below the latter. Thus it establishes the connection of the two carbon blocks with the conducting wire. As this screw has to go through the wooden cover, it will be best to use for it a wood screw, which, its head snapped off, is soldered into the binder. The binding-screws themselves are made of thick round brass.

For the zinc plate, which must be capable of being moved up and down, a guide must be made. We first cut from brass plate a strip, 3·5 cm. long and 13 mm. wide, and punch in it four holes, two to enable us to screw the strip in its place, one for the binding-screw to the right, and one for the guiding-pipe of the zinc plate. Into this last hole a socket of brass tubing, 2·5 cm. long, is soldered. The socket is for the rod on which the zinc hangs. Now the right-hand binding-screw, which connects with the zinc, is riveted into the brass strip, and the guiding-rod is made from brass wire. The rod has a small disc of brass soldered on to its end and serving as a handle. At its lower end the rod is joined to the zinc plate by screws or by soldering. Of course, there must be no contact between the rod and the blocks of carbon between which it passes; it is likewise necessary that there should be a space between the left binding-screw, which is connected with the carbon, and the brass strip in which is fastened the binding-screw for the zinc. All being now ready, we, last of all, screw the brass strip on to the cover.

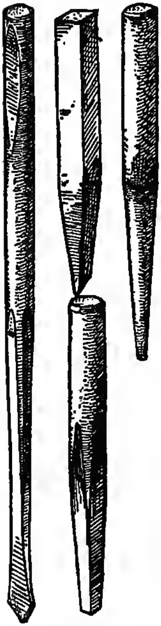
45. Ruler with square cross-section. The length of this ruler is 30 cm.; the thickness, 15 mm. The square iron is carefully made, the angles made true with the rough file, and the whole smoothed with a fine file. After the filing, the surfaces may be finished with coarse emery paper.



46. Ruler with chamfered edge. Length, 30 cm.; breadth, 30 mm.; thickness, 7 mm. The flat iron bar is prepared and filed. On one side a chamfer (5 mm. wide) is filed, and 15 mm. from one end an 8 mm. hole is drilled.



47. Handscrew. The bow is of flat iron, 20 mm. wide, 7 mm. thick. A piece 18 cm. long is cut off, and marks of division are made, so that one part is 2 cm. shorter than each of the two others. A small cut is made, which shows, when the iron is red-hot, where the bend is to be. The iron, heated to redness at the points of division, is fixed in the vice and bent at right angles. In the shorter arm we drill, 12 mm. from the end, an 8 mm. hole, and in it cut a screw with the 10 mm. screw-tap. The length of the inserted screw corresponds with that of the upright arm of the bow; the screw is made of round bar iron, 10 mm. thick. At one end of it, a cut, 1 cm. long, is made with the saw, and a square ear of iron plate (3 mm. thick) let into the cut. Screw and ear are then hard soldered (*i.e.* soldered with brass). The ear when cold may be worked with the file into an elegant form, say, a heart shape. On the other end of the screw a round tenon is cut, and then the thread is made with the screw-stock, so that the screw just fits into the female screw. A small cup is fixed on the round tenon at the top of the screw. This cup is about 25 mm. in diameter, and is made from iron plate, 1 mm. thick, cut round, and then shaped with the punch on a sheet of lead. The size of the hole in the cup must correspond with that of the tenon, so that the cup can turn on the tenon. Bow and ear of screw are now filed with rough and bastard files, and the tenon somewhat flattened at the end, so that the cup may not fall off.

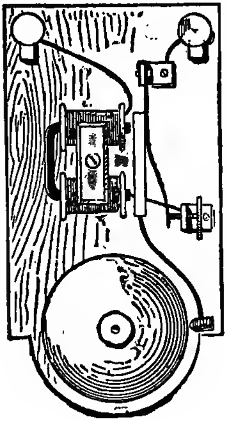


48. **Tools—chisels, punches, drills.** All these tools are made of cast steel, 8 mm. thick, and are from 8 to 10 cm. long. The cast steel is heated to redness, beaten out somewhat on the anvil—the chisel on two sides, so that an edge is formed; the four-cornered punch on four sides, but so as to leave at the end a square surface of 3 or 4 mm. side. The round hollow punch is beaten to a circle at the end, and also has there a surface 3 or 4 mm. in diameter. Lastly, of the drill. The metal is beaten out on four sides, and then flattened on one side to the thickness of 1·5 mm.; the breadth will depend on the size of the hole which we propose to drill with it. The tool-ends remain on the bar during the hammering process, so that they may be the better held. It is only after the hammering that the mark of division is cut into with the triangular file; we then fix the bar in the vice up to the point indicated, and break off. Afterwards we use rough file and finer file on the

detached pieces, according to the purposes for which they are intended. This done, they are again heated to redness in the fire, and cooled off in clean cold water, cooled, however, only for about 1·5 cm. of their length, so that the heat remaining can do the blueing. The cooled part is rubbed with sandstone until one can see the colours—yellow, red, and blue. If the blue is duly there, the whole tool is again cooled, and will now possess the requisite hardness. (See *Bericht der Lehrerbildungsanstalt für* 1891.)

49. Metal parts for cylinder of steam-engine. (See Bench-Work, No. 35.) Axle and piston-rods are of iron wire, the cranks of brass. The two piston-rods have a screw made at the bottom and a loop at the top. The cranks are cut of brass 6 cm. long, and a slit is filed in their lower ends. It is in the slit that the loops on the piston-rods move. Small holes are drilled through the sides of the slits, and bolts are fixed through these holes to catch the loops. In the cranks, beginning at the middle of their long sides, we file the metal away towards the back top corners, and thus produce a cavity in which the wire of the axle can turn freely. To keep the axle from leaving the crank when rotation takes place, we bore through the crank in a direction at right angles to the axle, small holes, make female screws in these holes, and then fit in small screws. The axle is thus connected with the cranks. The wire of the axle is bent into rectangular loops, the depth of the loop depending on the height to which the parts of the cylinder are lifted. In our model, the bend for the piston is 2·5 cm. deep, for the block illustrating the action of the valves 1·5 cm. The end of the axle which projects beyond the frame is hammered flat, then pointed, and fixed in the turning-disc. Lastly, in the other side of the disc, we fasten a small iron rod to serve as a handle enabling us to work the machine.

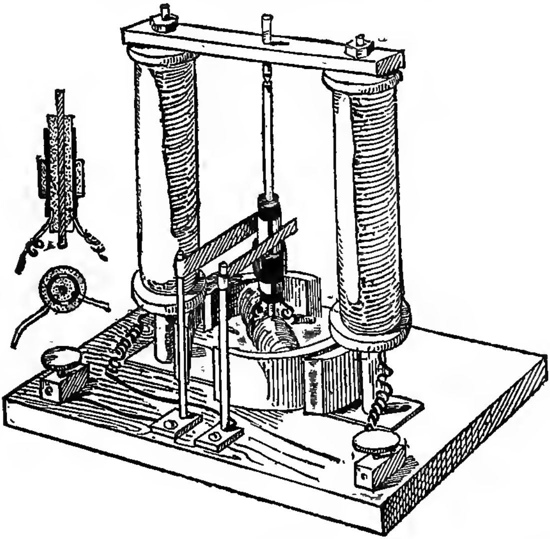
50. Electric bell. This arrangement is familiar enough; it must, nevertheless, not be missing from our course. The various parts are mounted on a small board, as shown. The electro-magnet consists of a bow of iron wire, 7 mm. thick, on which are the coils of copper wire about the iron cores.



The magnet is fastened to the board by means of a strip of wood, through which passes a wood screw drawing the strip towards the board. In front of the magnet is an armature of soft iron, into a hole in which the hammer of the bell is soldered fast. On the outside of the armature a spring is soldered. This spring is, at its upper end, fastened sideways by means of screws in a brass cramp screwed on to the board. The lower, movable end of the spring passes to a second cramp, also of brass, and also secured to the board by screws. Through the arm of the cramp which stands out from the board a screw works, and is so arranged that, when the machine is at rest, its end is in contact with the spring; whereas, as soon as the armature is attracted by the magnet, the spring leaves the screw. At the right and left top corners of the board binding-screws are fastened, and to them the wires from the battery lead. The bell, 9 cm. in diameter, is beaten out from brass plate. It rests on a pin of brass wire, the ends of which are filed down, and have screws threaded on them. The pin is fastened to the board by a nut underneath, fitting into a hole made for the purpose. This nut is of brass plate, and is rectangular; another nut of the same material, but round, secures the bell to the pin.

One end of the copper wire coiled round the magnet is connected with the binding-screw to the left; the other leads across to the lower brass cramp, and establishes the connection therewith. From the lower the current is conducted through the spring to the upper cramp, which in its turn is connected with the binding-screw to the right, so that the circuit is thus completed. As soon as the current circles round the magnet, the armature is attracted, the hammer strikes the bell and causes it to sound. The current is, however, interrupted; for with the movement of the armature the spring is removed from the screw on which it lay. The magnet loses its power of attracting; consequently the armature, drawn by a spring, reverts to its old position. The circuit is thus again completed, and the process begins anew.

51. Rotation apparatus. A composite work, the masterpiece of the course, yet not so difficult after the preceding exercises that a boy will be unable to cope with it.



It is a contrivance for utilising the attractive forceof anelectromagnet to produce continual motion. Instead of a horseshoe magnet, which, as it can only be bent while the metal is hot, is harder to make, we use two pillars of round bar iron. These pillars are 11·5 cm. high, and 10 mm. thick, and are joined at the top by a cross-piece of flat bar iron, 10 cm. long, 1·5 cm. wide, and 5 mm. thick. Both pillars are filed down at top and bottom, and screws are threaded. The screws at the bottom enable us to fasten the pillars to the base-board. This is done by means of nuts screwed upwards and resting in holes made to receive them. The screws at the bottom serve for uniting the pillars: for holes being bored in the proper places in the cross-piece, the latter is laid across the wire coils and attached to the pillars by nuts. On the upper surface of the base-board lies a strip of thin brass plate connecting the two pillars. This is fastened to the wood along with the pillars. It supplies a bed for the rotating axle, inasmuch as the conical lower extremity of the axle works in a small pit in the middle of it. The upper end of the axle has also a small pit made in it, the point of a screw passed through the middle of the cross-piece working in that pit. This screw and the axle are alike made of iron wire 3·5 mm. thick; the axle is 9·5 cm., and the screw 2·5 cm. long. Between the two pillars is a straight magnet turning with the rotating axle, to which it is affixed as follows:—The iron core in the straight electro-magnet has a hole drilled in the middle; the axle is then thrust through and soldered in its place. Instead, however, of soldering, we may drill a hole sideways in the iron (*i.e.* a hole perpendicular to the previous one), cut female screw, and insert therein a screw; this screw will bind the axle in position. The latter method is better, as, whilst the connection made is strong enough, the screw enables us to fix the rotating magnet higher or lower, as need may be.—To increase the mutual attraction and repulsion of the two electro-magnets, curved pieces of iron are affixed both on the inside at the base of the pillars, and at either end of the rotating magnet. These curved pieces or bows are made of hoop iron, 2 cm. broad, and 5 mm. thick, rounded over a mandrel. The two outer bows are cut, each 5 cm. long, the two inner each 4·5 cm. The ends are bevelled and neatly filed. In the middle of each piece a hole is made; the holes in the outer pieces enable us to rivet them to a flat surface filed on the pillars; those in the shorter pieces allow these to be riveted to the ends of the rotating magnet.

Near the front long-edge of the base-board are two binding-screws, made of brass in a way that will be by this time familiar (Metal-Work, No. 41). Between them, near the same edge of the board, and opposite the rotating axle, are two small uprights, 5·5 cm. high, and made of thick brass wire. These are soldered at the bottom into little squares of brass plate, the brass squares being attached to the board by screws. The tops of these uprights are filed down, and round them are soldered the looped ends of two strips of brass. The strips, 5 mm. deep, and hammered to act like a spring, are directed on to the axle, and work against a thickening of it in a way that will be understood from the side drawings, which give vertical and horizontal sections of the thickened axle. The thickening of the axle is produced as follows:—First we wrap several times round it, above the rotating magnet, a strip of paper, 3 cm. broad, and smeared with glue. The diameter of the paper cylinder thus produced should be 9 mm. To prevent this paper cylinder from slipping round the iron wire which forms its core, we, before rolling the cylinder, solder two bits of brass to opposite sides of the wire, and work them with the file so that they catch in the paper like hooks. We next make a socket of thin brass plate and cut it lengthways into two parts. The socket is 2·5 cm. long; the curve depends on that of the paper cylinder, upon which the two halves are so fixed that small strips of the paper are visible between them. Thus, when the machine is rotating, the two brass springs are alternately in contact with the half-sockets and with the paper of the cylinder. To keep the half-sockets in place, we roll round them another but narrower strip of paper, 9 mm. wide, and smeared as before with glue. The technical construction of the rotation apparatus is now finished.

The manner of connecting the wires is exhibited in the drawing. The wire is conducted from the right-hand (in drawing) binding-screw to the right-hand pillar, and coiled round it. At the top the wire passes under the iron cross-piece to the left-hand pillar, is coiled about it, and passes thence under the right-hand brass upright, the connection with the right-hand spring, the axle, etc., being thus established. A small piece of covered copper wire passes from the square plate in which the left-hand upright is fixed, to the left-hand binding-screw. In wrapping the rotating magnet, we place one end of the copper wire under one half of the brass socket, coil to one end of the magnet and back, then coil from the middle of the magnet to the other end and back, then thrust the end of the wire under the second half of the socket. The current passes from the right-hand binding-screw, in which has been fastened a conducting-wire from a battery, to the right-hand pillar, circulates round it, is conducted over the cross-piece to the left-hand pillar, circulates round that, passes to the right-hand brass upright and through the right-hand spring to one half-socket on the axle, then, circling round the rotating magnet, is conveyed to the other half-socket, thence to the left-hand spring and left-hand upright, and then from the foot of the latter to the left-hand binding-screw, in which the second conducting-wire from the battery has been fixed. The circuit is thus complete.

We may now explain by reference to the drawing the principle on which the rotation is produced. If the right-hand binding-screw is connected with the positive pole of the battery, the foot of the right-hand pillar is a south pole, that of the left-hand pillar a north pole. As long as the current passes from the half-socket which is now to the right end of the rotating magnet, that end becomes a north pole, the left end a south pole. Thus, the right-hand pillar and the left-hand end of the rotating magnet, as on the other side the pole of the left-hand pillar and the left-hand end of the rotating magnet, will attract each other, the axle carrying the horizontal magnet revolving from left to right. If the poles of the rotating magnet were unchangeable, the revolution would cease as soon as the revolving magnets were just between the pillars. But at the moment when this position is reached, the springs leave the half-sockets with which they have hitherto been in contact, the current is interrupted, both magnets become demagnetised, and the attraction ceases. Impetus causes the movable magnet to turn a little farther; whereupon the relations are changed. The circuit is again completed, but the current now circulates round the rotating magnet in the opposite direction, the poles change, and are consequently now repelled by the poles on the pillars which before attracted them. The result is rotation in the same direction as before. As soon as the rotating magnet again comes half-way between the pillars, its poles are again changed, and so the rotation is continued. If the work be carefully done, rapid rotation will be produced, to the great satisfaction of the workman.

D. WORKING IN GLASS.

We do not propose to make Glass-Work a separate and independent course, but rather to treat it as subsidiary to the other courses we have suggested. We may point out that the work is at once necessary and easy to learn. It enables us to produce a large number of *Anschauungsmittel* and much apparatus for school instruction, the making of which we should have to renounce if we excluded exercises in the simple manipulation of glass. Those who are willing to employ a glass-cutter can, of course, dispense with such exercises; but as we desire to be of service to those also who wish to be independent of all assistance, we have in the following pages brought together a series of examples of Glass-Work regarded as a complement to previous courses.

As, then, our task was to set our young workmen to completing models already made, and not to exhibit in systematic order by means of special objects the various ways of treating glass, we were confronted by a difficulty. We had to avoid proposing work involving various processes, lest a simple introductory exercise should be found combined with another and far harder one, requiring long practice before it could be done to perfection. We have met the difficulty by arranging the tasks in groups. In each group more than one kind of work is called for; but due care has been taken to present technical difficulties in an ascending series.

a. GLASS-CUTTING, SMOOTHING EDGES, ROUGHING.

1. **Cutting a piece of glass** for the apparatus to exhibit the unequal expansion of metals by heat. (See Bench-Work, No. 17; Metal-Work, Nos. 20 and 28.) To reduce as far as possible the friction of the index wire on its support when the metal bars are heated, we cut a strip of glass of the same width as the support, and of suitable length. The glass is fastened on with sealing-wax.

2. **Cutting sheets of glass** for the two devices to illustrate the refraction of light. (See Bench-Work, Nos. 31a and 31b; Metal-Work, No. 33.) The shape of the sheets is easily seen in the plates to Bench-Work, Nos. 31a and 31b.

3. **Cutting of two equal mirrors** for the corner mirror. (See Cardboard-Work, No. 18.)

4. **Cutting of two equal mirrors** for the "light echo" described in Cardboard-Work, No 31. The mirrors, having to fit exactly into the supports, must be cut carefully to measure.

5. **Cutting of four rectangular mirrors** for the "looking round the corner" apparatus. (See Cardboard-Work, No. 44.)

6. **Cutting of a small rectangular mirror** to illustrate the optical law, The angle of reflection of a ray of light is equal to the angle of incidence. (See Cardboard-Work, No. 33.)

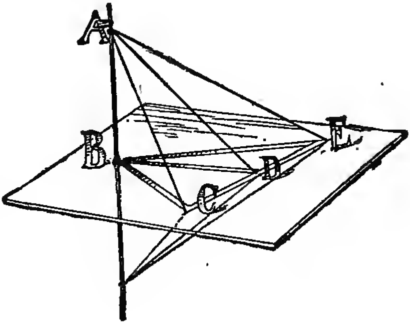
7. **Cutting of a mirror and two squares of glass, and roughing of the latter**—for the camera obscura. (See Cardboard-Work, No. 50.)

8. **Cutting of a round sheet of glass** for the exhibition of electric attraction and repulsion. (See Cardboard-Work, No. 41.)

9. **Cutting of three rectangular and two round pieces of glass, and roughing of one of the latter**—for the kaleidoscope. (See Cardboard-Work, No. 47.)

b. GLASS-BORING AND JOINING, MOUNTING ON GLASS.

10. **Anschauungsmittel for Solid Geometry.** The making of one such model for the proof of the theorems of Solid Geometry is sufficient to show the general method of constructing them. The model represented by the drawing serves to establish the theorem :—If a straight line stand at right angles to each of two straight lines at the point of their intersection, it shall also be at right angles to the plane which passes through them—that is, to the plane in which they are (Euclid XI. 4).



The plane is represented by the sheet of glass; the straight line at right angles to it by a piece of iron wire on which, above and below the glass, a small piece of metal is soldered to keep the wire in position. The straight lines lying in the plane are to be cut in thin white cardboard and secured to the glass; the letters are also cut from cardboard and mounted in their proper places. The lines of construction, AC, AD, AE, drawn from the perpendicular to points in the plane, are represented by pieces of thread or string.

The cutting of glass, already practised by the pupil, reappears here; technically new is the boring of the holes through the glass plate. This is done with a drill, the point of which has been hardened for the purpose, turpentine being dropped on from time to time as one drills.

11. Cementing three glasses in an insulating stool. (See Bench-Work, No. 6.)

12. Covering the Leyden jar with tinfoil both inside and outside. (See Metal-Work, No. 27.) A fairly large glass jar is used. The inside is covered first. (See Weinhold, *Vorschule*, p. 402.)

c. CUTTING GLASS TUBES INTO PARTS, SPRINGING, BENDING, AND DRAWING OUT GLASS.

13. Glass handle for the electrophorus. (See Metal-Work, No. 25.) The method of dividing a glass tube is as follows:—Scratch one side of the tube at the required point with a triangular file moistened with turpentine; place both thumbs on the glass opposite to the scratch and break off the piece desired. The sharp edges may be rounded by heating the ends until the glass begins to melt; the edges will then round themselves. The glass handle thus obtained is puttied into the socket for its reception already soldered on to the cover of the electrophorus.

14. Lightning tube. (See Metal-Work, No. 30.) Here we have practice in the dividing of thicker tubes. We file the place where the division is required fairly deep all round, moistening with turpentine as we file; we then try to break or else spring the tube along the scratched line by means of *Sprengkohle.*[1] The sharp edges may in this case be ground smooth on a stone. The spangles of tinfoil are cut with the chisel and placed in a spiral form round the tube from end to end. To attach them, use thin glue.

15. Electroscope. (See Metal-Work, No. 32.) For the foot we use an inverted wine-glass, to which is joined a short-necked flask. The neck of this flask is ground flat and a perforated cork inserted. Into the hole in the cork a piece of glass tubing is fixed, in order that the brass wire which supports the two aluminium leaves may be properly insulated. The brass wire is fixed with putty in the glass tube.

16. Chromic acid element. (See Bench-Work, No. 25; Metal-Work, No. 44.) We have here an exercise in springing glass. The process is as follows:—At each side of the place where the glass is to be sprung, bind with string a piece of paper 2 or 3 cm. wide, and rolled round to a thickness of 3 or 4 mm., so as to leave a space of only 2 or 3 mm. free between the rolls, a kind of groove or channel being thus formed. Next take a piece of good string, 2 or 3 mm. thick, tie one end to the screw of the front bench-vice, pass the string once round the glass to be sprung, and tie the other end to a strip of beech wood (50 × 2 or 3 × 0·5 cm.), fastened to the bench by means of the back bench-vice. When the string is drawn tight, saw quickly to and fro with the glass bottle until the string grows brown. As a rule, the glass of itself springs off smoothly; or a drop of water on the heated glass will assist the process. The sharp edges are ground on the outside with a slowly turned grindstone, on the inside filed away with a file moistened with oil of turpentine; or the whole rim may be ground level on a flat slab of sandstone. The brass rim is cemented outside the rim of the bottle thus sprung.

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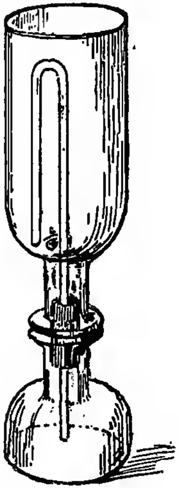
[1] "60 grs. of gum tragacanth are dissolved in sufficient water to make four liquid ounces of mucilage; 30 grains pulverised gum benzoin are then dissolved in the smallest possible quantity of spirits of wine; the two solutions are then mixed in a mortar, with enough pulverised and sifted beechwood charcoal to form a plastic mass." (Frick's *Physical Technics*, chap. ii., where see more on Glass-Work.)

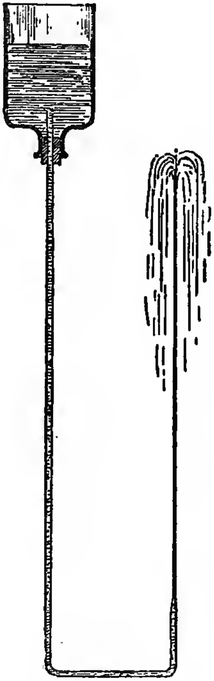
17. Induction apparatus. (See Metal-Work, No. 31.) The task here is simply to make a glass handle bent at a right angle, and serving to insulate the metal rod. Thus technically the only exercise is in bending glass. When the electric experiment is performed, the longer arm of the glass handle is fastened vertically in a retort-holder (see p. 130), whilst the shorter arm is passed horizontally through a hole in a cork; through a second hole, parallel to the first, the induction apparatus proper is secured, so that the latter is also horizontal during the experiment.

18. Glass arm with hook for insulating. (See Metal-Work, No. 36.) A piece of glass tubing is connected, in the way described under Metal-Work, with a stand to enable us to support pendulums, etc. Before making the connection, the free end is drawn out and bent into the form of a hook. In the drawing the glass arm is the lower one on the right.

19. Glass cup for magnetic needle. (See Metal-Work, No. 23.) The end of a piece of glass tubing is drawn out to a point and closed by melting. The closed conical piece at the end is scratched with the file and broken off, and then heated until sealing-wax melts on it. When the sealing-wax has grown cold, the cup is secured in the bend of the needle, the latter being also heated to the melting-point of the sealing-wax. The magnetic needle can now be balanced on the stand.

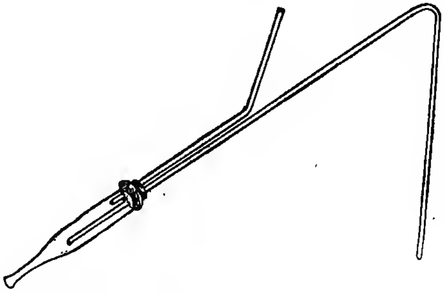
20. Magic cup. We use two medicine-bottles, the bottoms of which have been sprung off in the way already described. The two are joined by means of a cork through a hole in which is passed a bent glass tube. The bent part in the upper bottle acts as a siphon, so that when the upper vessel is filled with water until the latter comes above the bend in the tube, the outflow from the lower part of the vessel begins. The exercises which here find application are in springing glass and bending a glass tube.



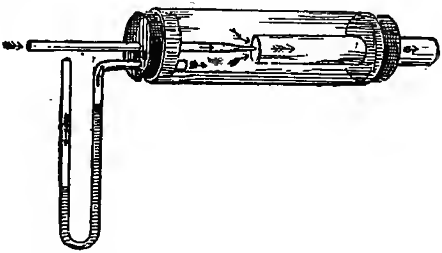


21. Fountain. A bottle, the bottom of which has been sprung off, serves as a reservoir. In the neck is inserted a cork, through which the end of a tube bent twice at right angles is passed. The other end of the tube is drawn out until the orifice is very small. Practise in springing glass bending tube, and drawing out.

22. Siphon with suction tube. A combination of two bent glass tubes with an elongated bottle, the bottom of which has been sprung off. The inside of the rim is filed away somewhat, and cork fitted tightly in. This cork has two holes bored through it to receive the two bent tubes, the siphon and the suction pipe. When suction is applied by means of the tube with the upward bend, the neck of the bottle, which is turned downwards, must, of course, be closed with the finger. Practise in dividing and bending tubes, as also in springing glass.



23. Air-sucker. A combination of wide and narrower straight and bent glass tubes. The wide glass tube is closed at both ends by means of corks, one of which is pierced once to receive the next widest tube, the other twice to receive a narrower straight tube drawn at the end towards a point, and a U-shaped tube. If we partly fill the U-shaped tube with coloured water, and then blow vigorously into the narrow straight tube, the current of air rushing through the tube second in width carries along with it the air contained in the widest of the tubes. This is rendered apparent by the rising of the coloured water in the arm of the bent tube



which leads into the cylinder, the pressure of the air in the other arm forcing the water up. The sucking action of air currents is thus shown. Practise in dividing tubes, drawing them out towards a point, and bending them.

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